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**Sistema Opto-Mecánico para Evaluar la Respuesta
Macro y Micromecánica de Tejido Biológico Suave**

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Que para obtener el título de
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Resumen

En este trabajo se presenta el proceso de diseño e implementación de un sistema integral portátil para la caracterización de propiedades mecánicas de materiales biológicos con comportamiento mecánico tipo elastómero. Se describen los componentes mecánicos y electrónicos utilizados en su integración, así como el instrumento virtual (VI) especialmente desarrollado para sincronizar su funcionamiento y realizar la adquisición de datos de las variables de interés en este trabajo. Además se muestra la metodología de análisis y la información obtenida de la muestra de tejido biológico estudiado (pericardio bovino); los resultados de dicha prueba nos permitieron lograr un mejor entendimiento de la respuesta macromecánica del pericardio bovino, bajo tracción uniaxial, en términos de su respuesta micromecánica, es decir la interacción entre las fibras de colágeno. A través de los campos vectoriales de desplazamiento y deformación se logró observar la existencia de deformaciones no homogéneas en el pericardio bovino, lo que llevó a registrar variaciones en sus propiedades mecánicas como en los módulos de elasticidad y de corte. Los resultados obtenidos con el presente dispositivo, concordaron con aquellos reportados en la literatura para el pericardio bovino. Por lo anterior, se puede concluir que el dispositivo es adecuado para determinar las propiedades macro y micromecánicas de materiales suaves y tejido biológico. Es importante mencionar que actualmente, este dispositivo es un desarrollo tecnológico que ha apoyado en las actividades de varios grupos de investigación dentro y fuera de nuestra Universidad.

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Introducción

Una forma de determinar las propiedades mecánicas de los materiales es mediante el ensayo de tracción uniaxial; desafortunadamente, la gran mayoría de los equipos comercialmente disponibles para esta finalidad están orientados a la caracterización de materiales de gran rigidez como pueden ser los metales, resultando inadecuados para la caracterización de materiales suaves y elásticos. Es por eso que se buscó desarrollar un dispositivo que resultara adecuado para ensayar dichos materiales y permita conocer sus propiedades mecánicas desde las escalas macro y micromecánica de una manera simultánea. En este proyecto, se seleccionaron cuidadosamente componentes y actuadores en la escala adecuada para estudiar los materiales de interés. Los sensores y actuadores fueron caracterizados y calibrados para ser integrados en un dispositivo portátil y funcional. Se desarrolló un instrumento virtual (VI) que permite controlar, visualizar y adquirir los datos obtenidos de los elementos ya integrados de una manera síncrona. A continuación se hicieron experimentos de validación en materiales bien conocidos y ampliamente caracterizados en la literatura. –Dichas pruebas permitieron la validación del funcionamiento del sistema al comparar los resultados obtenidos de los materiales de control con los reportados en la literatura.– Finalmente, se realizaron pruebas en el pericardio bovino liofilizado tratado con glutaraldehído. De los resultados obtenidos se puede concluir que el dispositivo cumple cabalmente con el objetivo de funcionamiento. También se pudo deducir que es posible utilizar la metodología de análisis presentada para determinar de manera simultánea y precisa las propiedades micro y macromecánicas de este tipo de materiales bajo tracción uniaxial. La utilidad del conocimiento de las propiedades de estos materiales radica en poder elegir su campo de aplicación adecuadamente, así como comprender las posibles variaciones de estas características mediante algún tratamiento químico para mejorarlas o adecuarlas a una aplicación específica. Conocer el comportamiento micromecánico de biopolímeros y tejidos biológicos resulta de particular importancia en aplicaciones médicas en las que un estudio local del tejido es requerido para lograr una mejor selección del material

a utilizar en la aplicación. Un ejemplo de lo anterior se encuentra en las propiedades micromecánicas del pericardio bovino que es utilizado en el desarrollo de bioprótesis cardiacas. Las bioprótesis cardiacas pueden experimentar cambios locales debido a procesos fisicoquímicos o fisiológicos alterando la respuesta mecánica de las valvas de pericardio bovino utilizado en la bioprótesis; resultando en un mal funcionamiento de la misma. Es por lo anterior que al realizar un análisis mas detallado de la respuesta macro y micromecánica de este tipo de materiales podría llevarse a cabo una mejor selección de los mismos y evitar futuras complicaciones en las diversas aplicaciones.

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Antecedentes

1.1. Comportamiento mecánico

Hoy en día determinar el comportamiento mecánico de materiales biológicos sigue siendo un reto para quienes diseñan y habilitan experimentos para dicho fin. Estudiar este tipo de materiales no es sencillo ya que en la mayoría de las ocasiones presentan espesores reducidos y generalmente son muy suaves. Como ejemplo de lo anterior tenemos a los tejidos biológicos, andamios celulares, hidrogeles así como películas poliméricas con comportamiento tipo elastómero.

Dentro de las propiedades mecánicas a determinar en dichos materiales destacan, el módulo de elasticidad, módulo de corte, tracción última de ruptura, deformación máxima, entre otras [1, 8]. Una de las pruebas que se utiliza de manera recurrente, para evaluar algunas de las propiedades mecánicas (módulo de elasticidad, resistencia última a la tensión, esfuerzo de cedencia, etc.), es el ensayo de tracción uniaxial. Así mismo, existen otro tipo de ensayos que involucran la dependencia del comportamiento mecánico en función del tiempo; tal es el caso, de las pruebas de relajación de esfuerzos y la prueba de cedencia. Estas dos últimas pruebas quedan fuera de los objetivos de este trabajo. Cabe mencionar que para realizar los experimentos de relajación de esfuerzos o la prueba de cedencia, el registro y control de la variable tiempo durante los experimentos es muy importante. La variable tiempo es de utilidad para definir la rapidez de deformación (0.16[mm/s]) a la que se deben ensayar las probetas; por lo tanto, se deben respetar los parámetros marcados por los estándares internacionales como la norma ASTM D882. En este punto debe hacerse hincapié en que para realizar las pruebas mecánicas en donde existe una fuerte dependencia de la variable tiempo, debe

tenerse en consideración los tiempos de muestreo y frecuencias de adquisición de datos. En el caso concreto de los tiempos críticos de relajación de esfuerzos para el pericardio bovino, se sitúan en tiempos cercanos a los 2 y 5 [s] observándose que después de los 20 [s] ya no se aprecia una disminución significativa en los esfuerzos, aún para razones de elongación del orden de 0.35 [mm/mm] [10]. Lo anterior quiere decir que si se realiza la adquisición de datos en tiempos del orden de fracciones de segundos, el efecto de la relajación de esfuerzos durante el ensayo mecánico será minimizado.

Para realizar los ensayos de tracción uniaxial ya existen equipos comerciales; sin embargo, estos equipos frecuentemente no siempre satisfacen los requerimientos del experimento. Esto se debe a que dichos equipos no fueron expresamente diseñados para ensayar materiales suaves; por el contrario, fueron diseñados para evaluar el comportamiento mecánico de los metales. Otro problema recurrente se encuentra en el tipo de análisis que ofrece el software de los equipos comerciales; pues al ser pensados para estudiar metales; un usuario con poca experiencia puede cometer el error de analizar los datos de un tejido biológico como si se tratase de un metal. En este punto es importante mencionar que los tejidos biológicos suaves presentarán un comportamiento mecánico no lineal y que claramente no satisfacen la ley de Hooke.

1.2. Modelos hiperelásticos

Las curvas esfuerzo *vs* razón de elongación de los tejidos biológicos suaves tienden a presentar grandes deformaciones con incrementos de esfuerzo muy reducidos. Debido a lo anterior, el modelo matemático que mejor describe el comportamiento mecánico de este tipo de materiales es el de Mooney-Rivlin [9, 13]; sin embargo, para algunos tejidos biológicos en condiciones de carga como la tracción uniaxial, el modelo de Mooney-Rivlin puede simplificarse y convertirse en el modelo conocido como Neo-Hooke [15].

Los métodos convencionales para determinar propiedades mecánicas tales como módulo de elasticidad, esfuerzo de cedencia, resistencia última a la tracción presentan características que resultan ventajosas para su aplicación en condiciones específicas. Es claro que hay que tener en cuenta algunas consideraciones y precauciones para lograr una correcta evaluación del material; entre ellas, una adecuada sujeción para evitar desplazamientos no deseados y considerar también los rangos de fuerza que se requieren para ensayar el material. Esto último lleva a una mejor selección del sensor de fuerza en cuanto a capacidad y sensibilidad; traduciéndose en datos experimentales más confiables.

Algunos métodos clasificados como alternativos se basan en métodos convencionales

en combinación con técnicas de microscopía e imagenología. Dicha combinación permite la obtención de lecturas más precisas con menos elementos en contacto con la muestra que pudieran intervenir en las mediciones y a la vez evitar la naturaleza destructiva de los ensayos[1].

1.2.1. Propiedades mecánicas de interés del pericardio

La caracterización de las propiedades de materiales elastoméricos tales como módulo elástico, módulo de corte, la tracción última a la ruptura no solo permiten conocer el comportamiento mecánico del material sino también aplicar dicha información a métodos de fabricación o tratamientos que mejoren dichas propiedades de acuerdo a las necesidades de la aplicación [2, 5]. Una de las técnicas encontradas para el mejoramiento de las propiedades mecánicas de un material es el uso de los llamados agentes entrecruzantes químicos como el glutaraldehído. Estos permiten el entrecruzamiento de las fibras de material. Los ensayos realizados en este tipo de estudios muestran curvas de concentración de la sustancia entrecruzante, la densidad de los entrecruzamientos en el material y el efecto en sus propiedades fisicoquímicas [7, 11]. Lo anterior se vuelve relevante cuando los agentes entrecruzantes deben utilizarse para modificar las propiedades fisicoquímicas de materiales biológicos como el pericardio bovino. En particular, el pericardio bovino es utilizado para desarrollar las valvas en las denominadas válvulas cardíacas biológicas que ayudan en el tratamiento de cardiopatías. Existen cardiopatías ya sea congénitas ó atribuibles a la edad que están directamente relacionadas al mal funcionamiento de las válvulas mitral y aortica como la regurgitación o la estenosis por calcificación [4, 6, 18, 21].

1.2.2. Estructura del pericardio

El pericardio, en los mamíferos, en general es un tejido compuesto por colágeno, elastina, agua y (ground substance o matriz extracelular) un sustrato compuesto de mucopolisacáridos, glicoproteínas y proteínas solubles. Se ha demostrado que las propiedades mecánicas del pericardio bovino mejoran al ser tratadas con glutaraldehído [14, 19], ya que es capaz de entrecruzar las fibras de colágeno mediante enlaces covalentes formando entrecruzamientos más numerosos que los encontrados naturalmente.

Pese a la importancia de las aplicaciones del pericardio, la mayoría de los estudios anteriores se enfocaban en la biocompatibilidad, el comportamiento mecánico macroscópico y su respuesta en el tiempo al encontrarse en el medio biológico; en donde la calcificación es uno de los problemas comúnmente encontrados [17].

1.3. Estado del arte

En reportes recientes se ha estudiado el comportamiento micromecánico del material revelando aspectos importantes de su naturaleza. Entre estos se puede mencionar la resistencia a la tracción en función del ángulo formado entre la dirección de la carga aplicada y la orientación de las fibras de la muestra. En dicho estudio se reporta que la curva esfuerzo *vs* razón de elongación presenta tres zonas bien definidas. En cada una de ellas, las fibras ofrecen distinta resistencia mecánica de acuerdo a su acomodo respecto a la dirección de aplicación de la carga. En la primera zona de la curva, las fibras ofrecen poca resistencia mecánica y presenta gran desplazamiento. En la segunda zona, las fibras empiezan a alinearse con la dirección de la carga aplicada y el esfuerzo registrado es significativamente mayor al de la primer zona. En la ultima zona algunas fibras comienzan a romperse y ocasionan un estado de esfuerzos diferente al impuesto por la tracción uniaxial. En esta ultima zona se hacen presentes esfuerzos de tipo cortante registrados por correlación de imágenes digitales [15].

La correlación de imágenes digitales (DIC, por sus siglas en inglés) es una técnica óptica que permite examinar materiales sin entrar en contacto con ellos. Para hacerlo, se requiere la adquisición de imágenes de la superficie de la muestra. Esto puede realizarse durante un ensayo de tracción uniaxial para someter al material a una carga/ estado de esfuerzo conocido. DIC ubica regiones de interés con su respectiva distribución en la escala de grises sobre la superficie de la muestra y hace una subdivisión de la imagen en dichas regiones de interés. DIC establece un sistema de referencia y posiciones iniciales para cada región de interés (en la imagen de referencia) y posteriormente las compara en las imágenes subsecuentes. De esta manera al conocer la posición inicial y final de cada región de interés, se logra obtener el campo desplazamientos vectorial entre cada par de imágenes. Considerando que las imágenes digitales se registraron a través de un microscopio óptico (5X), la información que se obtiene del material estudiado se considera de carácter micromecánico. Una vez determinado el campo de desplazamientos, es posible determinar el campo de deformaciones a través de un modelo lineal de cinco parámetros, como se ha reportado previamente en la literatura [15, 16]. Existen otros medios de caracterización de tejidos sin contacto/minimo contacto, entre ellos el de mayor interés para este trabajo, el basado en el llamado efecto de láser aleatorio [12]. Polson y Vardeny [12] reportaron un procedimiento para relacionar las características de la estructura del tejido con su espectro de emisión luminosa. De este modo lograron diferenciar tejido sano de tejidos cancerosos de una manera efectiva.

A pesar de que hay varios trabajos dedicados a realizar estudios del comportamiento mecánico de materiales suaves como andamios para cultivo celular ó tejidos biológicos

empleados en la regeneración de tejidos [1, 5, 7, 8, 11]; nadie ha realizado estudios del comportamiento macro y micromecánico de estos materiales bajo tracción utilizando un sistema integral para la caracterización micromecánica de materiales suaves empleando análisis de imágenes digitales.

Dada la falta de dispositivos con las características antes mencionadas, se planteó la siguiente hipótesis y objetivos.

1.4. Hipótesis

Es posible construir un dispositivo integral que permita evaluar la respuesta mecánica de materiales elastoméricos combinando técnicas de análisis a nivel macro y micromecánico de mínimo contacto de manera simultánea.

1.5. Objetivo general

Instrumentar un sistema opto-mecánico capaz de adquirir datos de tiempo, fuerza, desplazamiento e imagen de la superficie del material deformado; todo esto de manera simultánea durante un ensayo de tracción uniaxial. Los datos adquiridos durante este ensayo permiten conocer la respuesta mecánica del material a un nivel global así como a nivel local mediante el análisis de imágenes. Con lo anterior será posible realizar predicciones más precisas sobre el comportamiento mecánico de materiales complejos como aquellos que presentan deformaciones no homogéneas.

1.6. Objetivos particulares

- Diseñar y construir un sistema integral para la caracterización macro y micromecánica de materiales suaves y tejido biológico.
- Seleccionar sensores, actuadores y tarjeta de adquisición de datos adecuados para la medición de las variables: fuerza, desplazamiento, capturar imágenes y registro de tiempo de manera síncrona durante una prueba de tracción uniaxial.
- Instrumentar sensores y actuadores para que puedan ser integrados en una interfaz gráfica de fácil manejo para el usuario.

1. ANTECEDENTES

- Desarrollar e implementar los circuitos electrónicos para la amplificación y acondicionamiento de señales necesarios para la instrumentación del sistema.
- Caracterizar y calibrar los sensores y actuadores que integrarán el sistema integral.
- Desarrollar un instrumento virtual (VI) e interfaz gráfica de control del sistema integral en LabVIEW.
- Realizar pruebas de control que aseguren el correcto funcionamiento del sistema, el instrumento virtual e interfaz gráfica en conjunto. Validación del sistema integral ensayando elastómeros control.
- Realizar pruebas en el material elastomérico de interés; en este caso pericardio bovino.
- Validar los resultados obtenidos comparándolos con aquellos reportados previamente en la literatura.

Metodología

2.1. Diseño del sistema opto-mecánico

El diseño de este sistema opto-mecánico se basó en las necesidades que surgen al ensayar materiales suaves y de espesores reducidos que típicamente se utilizan en la ingeniería de tejidos y medicina regenerativa. Para construir el sistema opto-mecánico se utilizaron componentes comerciales que se encuentran a la venta. Algunos otros se desarrollaron en el laboratorio a medida de las necesidades. Dichos componentes se agrupan por su función en dos sistemas que trabajan conjuntamente, como se indica en la Fig. 2.1.

El primero corresponde al sistema mecánico integrado por un actuador lineal, la ceda de carga y un LVDT (LVDT, por sus siglas en inglés) y el segundo es un sistema óptico compuesto por una fuente de luz blanca, una guía de onda y un subsistema de lentes acoplados a una cámara CCD, como se muestra en la Fig. 2.2. Además, hay componentes que podemos llamar complementarios como la tarjeta de adquisición de datos, la fuente de alimentación simétrica y una computadora de escritorio que también integran al sistema opto-mecánico. A continuación se describen brevemente cada uno de los componentes destacando sus características principales.

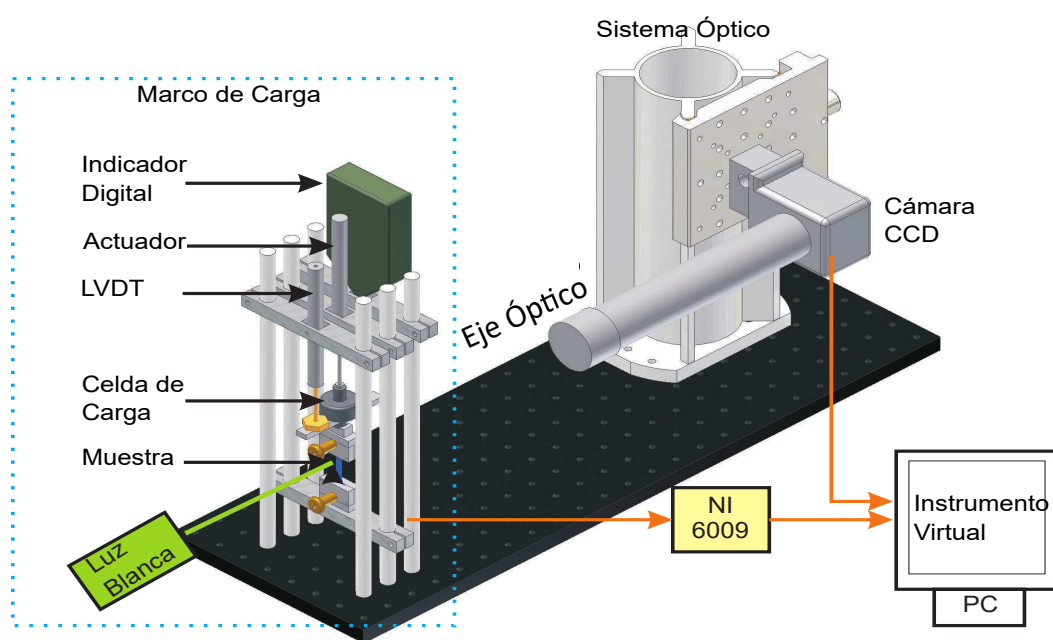


Figura 2.1: Montaje experimental del sistema opto-mecánico, en el que se esquematizan los componentes.

Sistema Integral Portátil.

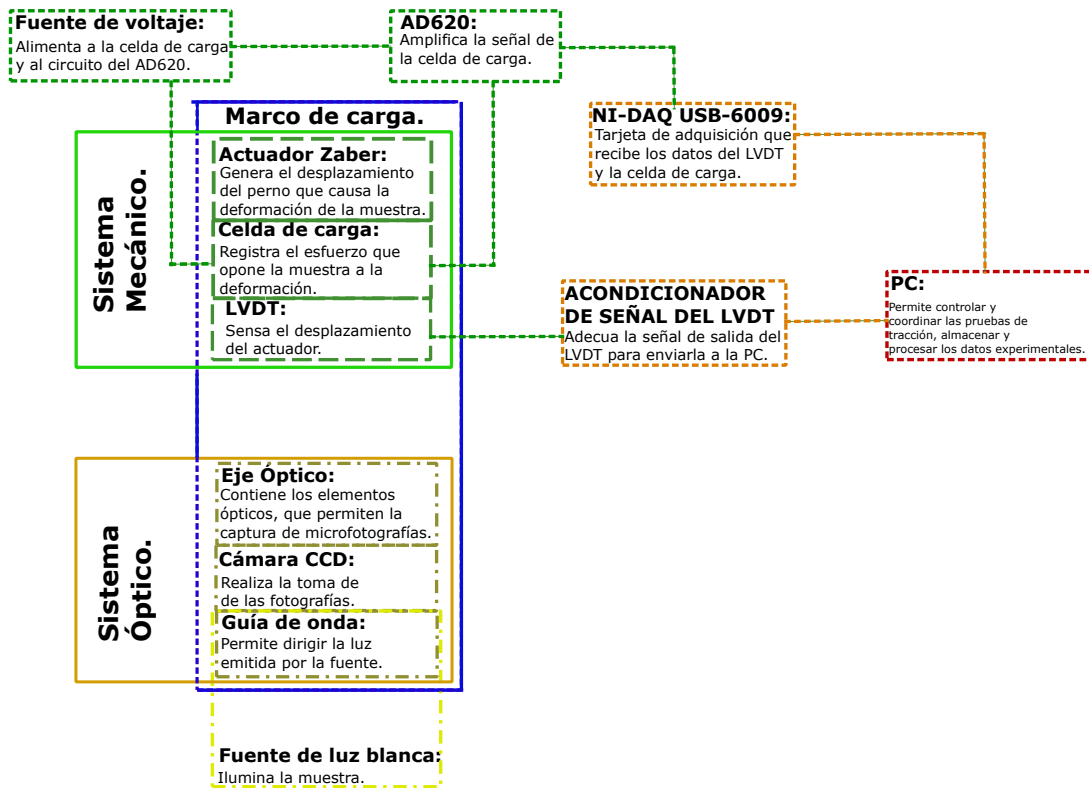


Figura 2.2: Diagrama de bloques que muestra los elementos que constituyen el sistema opto-mecánico agrupados en subsistemas y sus conexiones.

2.2. Elementos del sistema opto-mecánico

2.2.1. Marco de carga del sistema opto-mecánico

Se trata de una estructura rígida compuesta por una platina de aluminio (Thorlabs 60x25 cm) perforada de manera equidistante, postes de acero de 12 [mm] de diámetro y barras cuadradas de aluminio maquinadas para formar los cabezales del sistema. Esta estructura presenta una rigidez suficientemente alta para asegurar que no exista deformación por los esfuerzos generados durante la prueba de tracción uniaxial de los materiales suaves y espesor reducido. Además sirve de soporte para varios componentes del sistema opto-mecánico; tales como: la celda de carga, el LVDT, el actuador mecánico y las mordazas, como se muestra en la Fig. 2.1.

2.2.1.1. Celda de carga

Es un sensor de fuerza de la marca Sensotec con capacidad 9.81[N] en tracción/-compresión uniaxial, histéresis de $\pm 0.15\%$ en escala completa y resolución infinita de acuerdo al fabricante (Para mayores detalles consultar el apéndice A). Este componente es alimentado por una fuente simétrica con un voltaje de 5[V]; y la señal obtenida es amplificada mediante el circuito acondicionador AD620 que se describirá mas adelante. La curva de calibración y el modelo matemático de la misma fueron obtenidos mediante el muestreo de distintas masas patrón medidas en una balanza analítica. Para lograr una buena caracterización, se realizaron varios ciclos de carga y descarga; la información obtenida fue después procesada en Mathematica. Fig.2.3.

2.2.1.2. LVDT

Es un sensor de desplazamiento basado en un Transformador diferencial linealmente variable (Linear Variable Differential Transformer, LVDT por sus siglas en inglés) de la marca Lucas-Schaevits modelo MHR1000 con un rango de medición de ± 25.4 [mm], una sensibilidad de 27 [mV/V/mm] y error de no linealidad del 0.25% en carrera completa (Para mayores detalles consultar el apéndice B). Este sensor es capaz de ofrecer mediciones precisas en aplicaciones donde el espacio es restrictivo; cuenta con un núcleo muy ligero y por lo tanto con menor inercia. Lo anterior permite mediciones más precisas a mayor velocidad y con mayor facilidad Fig.2.4.

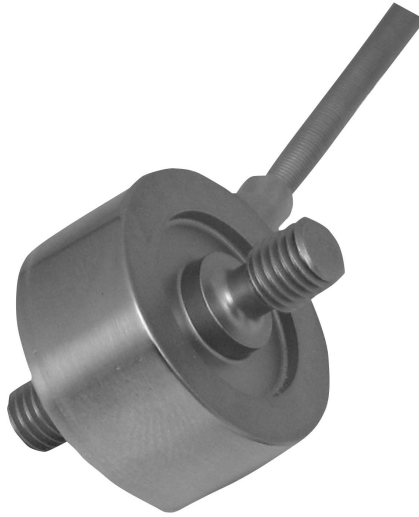


Figura 2.3: Celda de carga Sensotec/Honeywell.

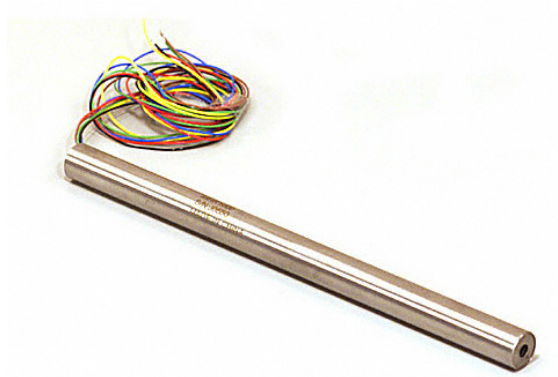


Figura 2.4: LVDT marca Lucas-Schaeffers modelo MHR1000.

2.2.1.3. Actuador mecánico lineal

El actuador mecánico lineal montado en el marco de carga, es un motor a pasos de la marca Zaber modelo T-LA28A con carrera de 28 [mm], velocidad máxima de 4[mm/s], y precisión de ± 12 [μm]. Se comprobaron algunas características como la velocidad y la precisión en el desplazamiento utilizando un medidor de desplazamiento de la marca Mitutoyo; se realizaron varios ciclos de extensión y contracción del husillo del actuador. Los datos obtenidos fueron analizados en Mathematica para su caracterización. Una de las ventajas de utilizar dicho actuador es que el fabricante provee un conjunto de instrumentos virtuales (VIs) para facilitar su integración con LabVIEW Fig. 2.5. Entre estos VI's, podemos encontrar un panel de control y subVI's que permiten programar parámetros de operación en memoria no volátil tales como "Home" (#1) que lleva el perno del actuador a la posición de inicio, "Set Home Speed" (#41) que permite ajustar la velocidad a la que el perno regresa a la posición de inicio ó "Set Target Speed" (#42) que establece la velocidad de desplazamiento del perno (Para mayores detalles consultar el apéndice C). Estos comandos nos permiten asegurar que el perno se desplaza a la velocidad de 0.16 [mm/s] como es indicado en la norma ASTM D882.



Figura 2.5: Actuador Mecánico lineal marca Zaber modelo T-LA28A.

2.2.2. Instrumentación

2.2.3. Fuente simétrica

La fuente de alimentación simétrica Fig. 2.6 fue construida usando un modelo sencillo de fuente de alimentación basado en un transformador de voltaje 127/24[V], un puente rectificador de diodos, los transistores de potencia TIP41, TIP42 y los circuitos

integrados LM317 para regular el voltaje positivo y su contraparte, el LM337 para el voltaje negativo. Tanto el LM317 como el LM337 tienen un rango de regulación de 1.2[V] a 37[V] y una corriente máxima de trabajo de hasta 1.5[A] y finalmente dos transistores de señal pequeña, el BC547 y el BC557 en las partes positiva y negativa respectivamente; esto nos permite asegurar que no hay variaciones de corriente o voltaje al conectar la carga a la fuente.

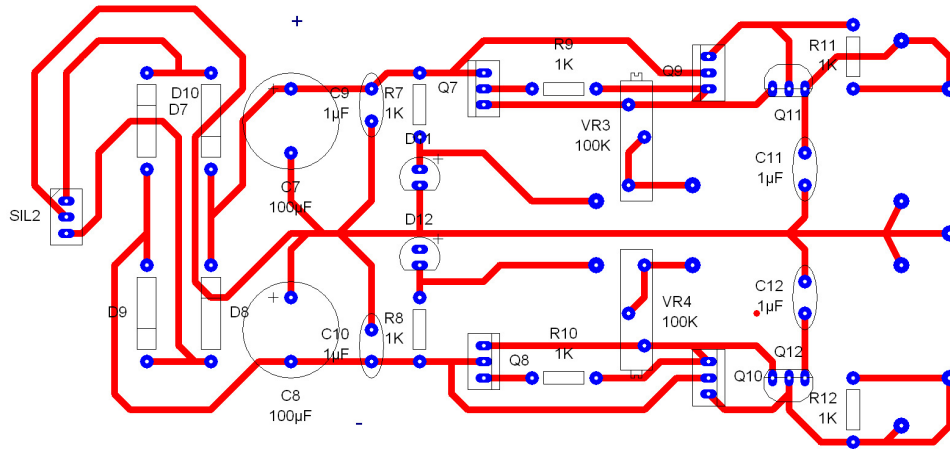


Figura 2.6: Diagrama esquemático de la fuente simétrica que alimenta la celda de carga y el amplificador de instrumentación AD620.

2.2.4. Circuito de acondicionamiento de señal.

El circuito acondicionador de señal que se muestra en la Fig. 2.7 está basado en el integrado AD620. El cual es en sí, un amplificador de instrumentación muy robusto y estable que permite obtener ganancias de 1 a 10000 veces la señal de entrada [v/v], con un rango de rechazo de ruido en modo común de 100 [dB] según datos del fabricante (Para mayores detalles consultar el apéndice D). Esto nos permite detectar señales muy pequeñas provenientes de la celda de carga y amplificarlas prácticamente sin interferencia. Para su operación, el circuito requiere de un elemento resistor externo que se implementó mediante una resistencia fija de 49.9[Ω] y un trimpot de 5.17[kΩ] (valor real) ajustado a 31.7[Ω]. Este circuito es alimentado por la fuente ya mencionada y su señal de salida se dirige a la tarjeta de adquisición de datos. Para calcular la ganancia

2. METODOLOGÍA

del circuito, el fabricante proporciona la siguiente expresión:

$$G = \frac{49.9[k\Omega]}{R_G} + 1 \quad (2.1)$$

El ajuste de la ganancia se adecuó a las especificaciones de voltaje del canal correspondiente de la tarjeta de adquisición de datos (NIDAQ-USB-6009) que es de $\pm 10[V]$, quedando:

$$G = \frac{49.9[k\Omega]}{49.9[\Omega] + 31.7[\Omega]} + 1 \approx 621 \left[\frac{\Omega}{\Omega} \right]$$

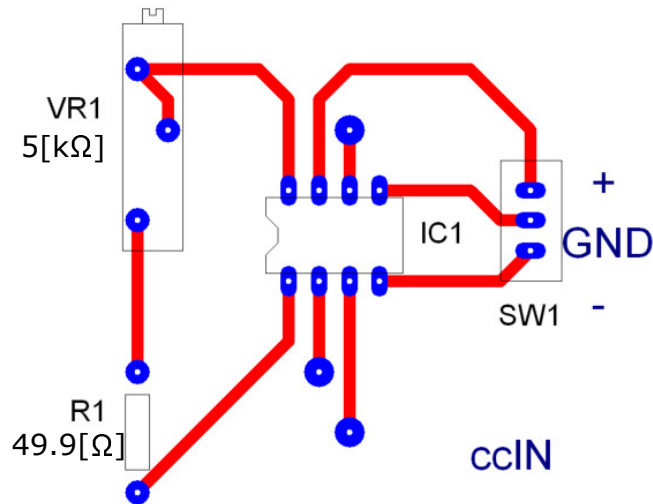


Figura 2.7: Diagrama esquemático del circuito basado en el amplificador de instrumentación AD620.

2.2.5. Tarjeta de Adquisición de datos.

Se utilizó una tarjeta de adquisición de datos NIDAQ-USB-6009 de la marca National Instruments. Esta tarjeta cuenta con una resolución de 14 bits en modo diferencial en cada una de sus entradas analógicas. Posee una velocidad máxima de muestreo es de $42[kS/s]$ en adquisición de canales múltiples y resolución de $41.67[ns]$. Este dispositivo

recibe las señales de salida de los acondicionadores de señal del LVDT y la celda de carga respectivamente para enviarlos a la computadora (PC) Fig.2.8. La configuración de parámetros de los puertos de la tarjeta de adquisición de datos se establece en la primera etapa del VI, quedando el reloj de muestreo en 1000, el número de muestras tomadas por segundo en 50; en una etapa más avanzada del VI, se realiza el promedio de los datos adquiridos en cada iteración.



Figura 2.8: Tarjeta de adquisición de datos NIDAQ-USB-6009.

2.2.6. Acondicionador de señal para el LVDT

Se trata de un acondicionador de señal modelo ATA2001 de la marca Lucas-Schaevits. Este acondicionador utiliza un microprocesador que genera una onda senoidal para controlar todas las funciones de calibración. Permite realizar ajustes tales como: Rango de supresión de cero, que permite ajustar la posición de la línea de salida a 0[V] en hasta un $\pm 110\%$ de la salida de escala completa, rango de compensación de cambio de fase, que permite el corrimiento de la onda senoidal en $\pm 120^\circ$, no linealidad e histéresis de $\pm 0.05\%$ máximas de la salida a escala completa y estabilidad de $\pm 0.05\%$ máxima de la salida a escala completa (Para mayores detalles consultar el apéndice F). El acondicionador también se utiliza para demodular, filtrar y sincronizar la señal del LVDT. Todas las características de configuración son almacenadas en memoria no volátil por lo que no hay riesgo de perder la configuración por falta de alimentación y por lo tanto es mínima la necesidad de repetir la calibración previa a un experimento Fig.2.9.



Figura 2.9: Acondicionador de señal para el LVDT.

2.2.7. Computadora de escritorio

Se utilizó una computadora de escritorio en la cual se instalaron controladores de los dispositivos, se desarrollo también un VI que coordine el funcionamiento de los elementos del sistema opto-mecánico y el almacenamiento de los datos e imágenes adquiridos de manera simultánea.

2.3. Sistema óptico

2.3.1. Cámara CCD

La adquisición de imágenes se realizó una cámara CCD de la marca Thorlabs modelo DCC1240C con un CCD de 1/3" y una resolución de 1280[H] x 1024[V] pixeles y con conexión por USB; así mismo, la cámara está acoplada a un subsistema óptico modular que incluye un adaptador Infinitube FM200 ensamblado para esta aplicación; permitiendo, obtener distintas magnificaciones a través de diferentes objetivos según sea necesario. Además, el adaptador InfinitiTube FM200 permite añadir y dirigir el haz de luz –generado por la fuente de iluminación– a través del eje óptico hasta hacerlo incidir sobre la superficie de la muestra de una manera precisa.

La configuración de parámetros de funcionamiento de la cámara (ganancia, tiempo de exposición, razón de cuadros por segundo, velocidad de actualización por pixel) se lleva a cabo mediante LabVIEW. Las imágenes capturadas por la cámara son almacenadas en la PC para su posterior análisis [2.10](#).



Figura 2.10: Cámara Thorlabs e Infnitube FM200.

2.3.2. Lámpara de luz blanca

Se utilizó una lámpara de luz blanca Fiber-Lite modelo PL-900; esta fuente de luz cuenta con una perilla de control de intensidad luminosa y un puerto de conector tipo D de 9 pines para controlarla remotamente. Se conectó una guía de onda (fibra óptica) a esta lámpara para poder dirigir de manera más precisa el haz de luz sobre las muestras durante los experimentos [2.11](#). Esta fuente permite regular la intensidad de la iluminación y lograr mayor calidad y definición en las imágenes.

2.4. Desarrollo de Instrumento Virtual

El funcionamiento del sistema opto-mecánico es controlado por un instrumento virtual (VI) especialmente desarrollado para este sistema. Dicho VI se programó en LabVIEW. Los detalles del código se mostrarán en la sección de resultados.



Figura 2.11: Fuente de luz blanca Fiber-Lite PL-900.

Resultados

3.1. Sistema opto-mecánico y su instrumento virtual

La integración de los componentes, dispositivos y el instrumento virtual ya mencionado, permitieron el desarrollo del sistema opto-mecánico, objetivo de este trabajo.

Uno de los principales resultados del presente trabajo es el sistema opto-mecánico (ver Fig. 3.1) y su instrumento virtual (VI) que facilita la integración de los dispositivos descritos en las secciones anteriores. En la Fig. 3.2 se muestra un esquema general del Instrumento Virtual. Para su análisis, este VI puede ser dividido en cuatro secciones de acuerdo a las funciones que se llevan a cabo en cada una de ellas. Podemos tomar como referencia cada uno de los rectángulos de la estructura de ejecución secuencial (llamada Flat Sequence Structure en el entorno LabVIEW), como se muestra en el diagrama de bloques de la Figura 3.2. Mismo que se describirán con mayor detalle en las siguiente sección.

3.2. Diagrama de bloques

3.2.1. Inicialización de variables y dispositivos.

Las funciones realizadas en la primera etapa del VI son: la definición de las variables a utilizar, selección de los puertos, comunicación e inicialización de dispositivos como se observa en la Fig. 3.3. En esta etapa también se inician: el acumulador que permite llevar el conteo de las iteraciones realizadas, la variable que almacena el desplazamiento

3. RESULTADOS

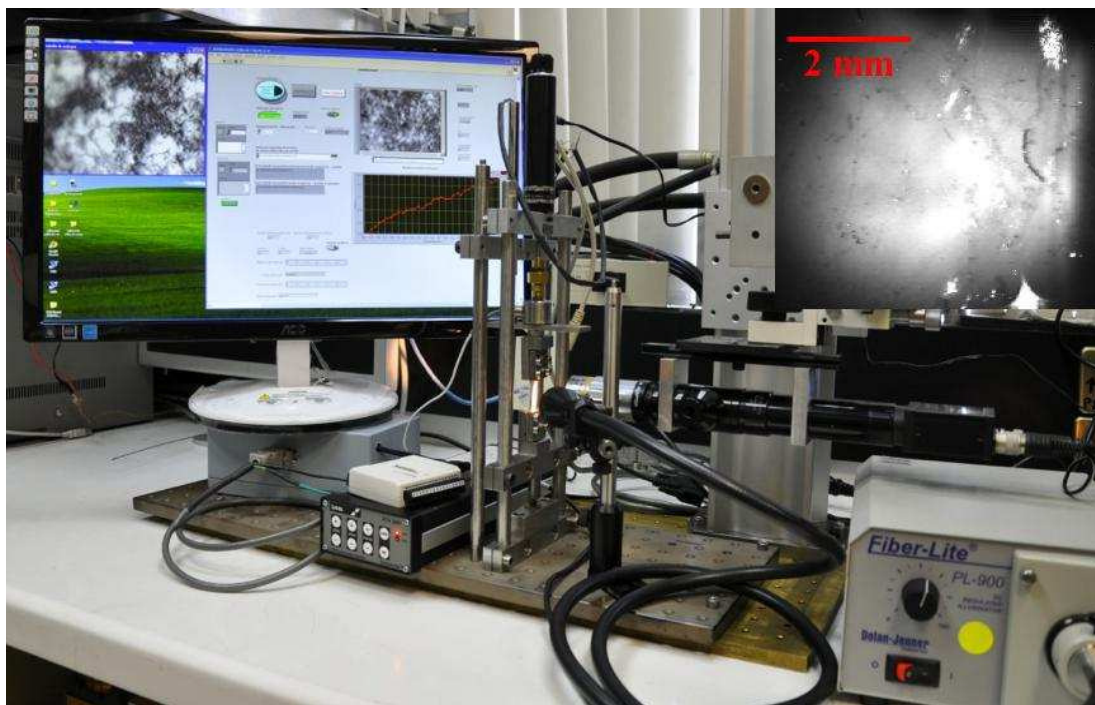


Figura 3.1: Vista del sistema opto-mecánico durante su operación.

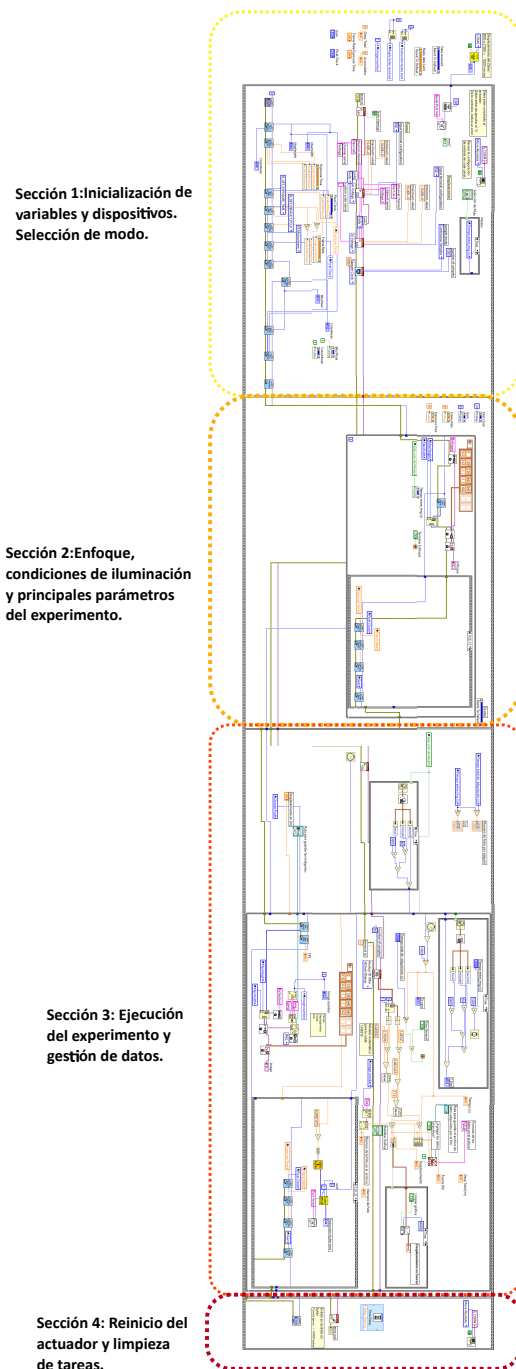


Figura 3.2: Diagrama de bloques completo del VI. De arriba hacia abajo tenemos las 4 secciones que lo componen: inicialización, ajustes y enfoque previo, gestión de datos y finalización de tareas.

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total del actuador, el número de foto capturada, el puerto definido para la comunicación con el actuador Zaber y los arreglos para manejar los bytes (instrucciones) enviados y la respuesta recibidas por el actuador. Esto ocurre al inicio y fuera del marco de ejecución de la secuencia principal del VI pues deben de estar disponibles globalmente.

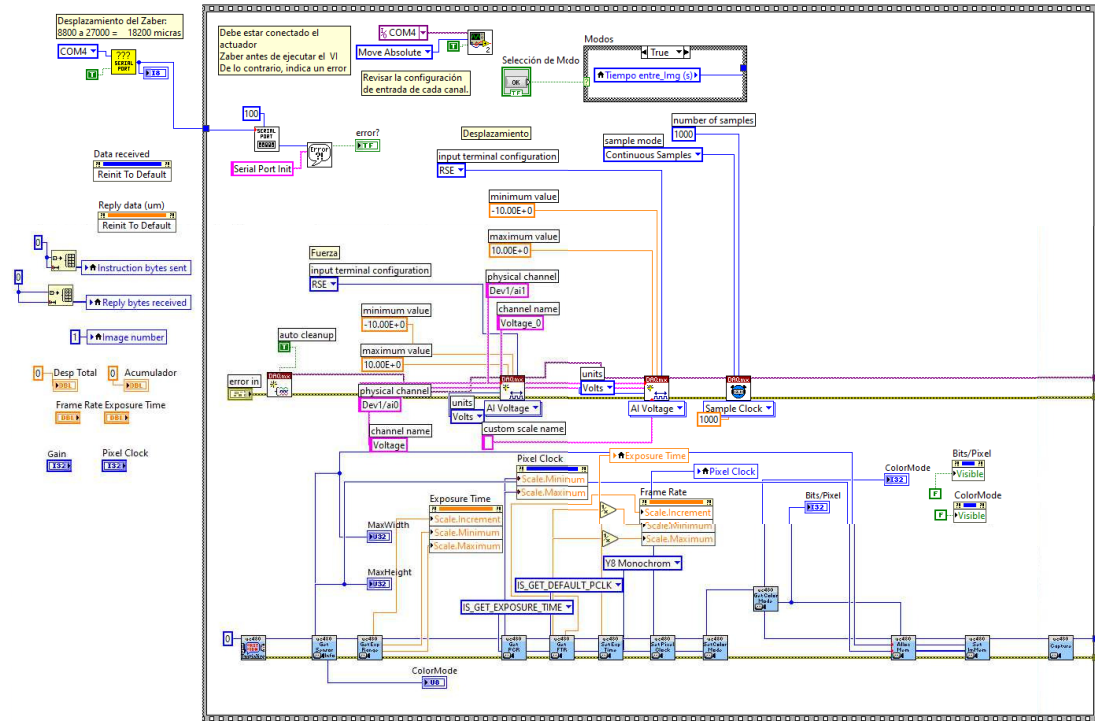


Figura 3.3: Se muestra la primera sección del VI, en el que se llevan a cabo la definición de variables, inicialización de periféricos y selección del modo de prueba. Las variables que aparecen fuera del bloque de secuencia debido a su condición de globales.

Dentro de la secuencia de ejecución del VI aún en la primera etapa encontramos la inicialización de puerto del actuador Zaber, la selección del modo de experimentación del VI, inicio de las tareas y canales de adquisición de datos además de detalles de la configuración de los mismos; también se da de alta la cámara USB, se obtienen sus parámetros de configuración por defecto y se prepara para la siguiente etapa.

3.2.2. Enfoque, iluminación y principales parámetros del experimento.

La segunda sección corresponde al segundo bloque de ejecución del VI; Fig. 3.4 en esta etapa podemos hacer los ajustes de parámetros de enfoque para la cámara, tales como tiempo de exposición (Exposure Time), ganancia (Gain), la velocidad de lectura (o actualización) del sensor (Pixel Clock) y la cantidad de cuadros por unidad de tiempo (Frame Rate). Los controles para hacer estos ajustes están presentes en el panel frontal del VI, permitiendo el ajuste antes o durante la prueba. Esto es importante ya que las imágenes obtenidas serán analizadas usando el método de correlación de imágenes digitales para obtener información sobre el material ensayado.

3.2.3. Modos de ejecución del experimento.

La tercera etapa del instrumento Fig. 3.5, da inicio al cronómetro del experimento; este cronómetro permite llevar el registro del tiempo y el control del experimento según el modo de ejecución elegido. Se programaron dos modos de ejecución; el modo tracción uniaxial continua y el modo de tracción uniaxial por pasos.

En el modo de tracción uniaxial continua se define, como entrada, la carrera total del husillo. Este valor debe permanecer dentro del rango permitido de la carrera total del actuador. También se define como dato de entrada el tamaño de paso del actuador. Cabe mencionar que el desplazamiento total del actuador es de 18200 [μm] y el tamaño de paso mas pequeño será de 10 [μm]. La velocidad de realización de la prueba puede variar de acuerdo a la capacidad de procesamiento de la PC, es decir, si la computadora no tiene los recursos suficientes, la prueba puede ralentizarse, esto puede estar relacionado con el hecho de que el actuador Zaber solo permite la comunicación cuando no se está desplazando el husillo, es decir, entre cada paso. Una desventaja de este modo de ejecución es que no se pueden obtener imágenes en tiempos definidos. Durante el experimento, el husillo se desplazará según el tamaño del paso que se haya indicado, luego se hará la captura de imagen de la muestra y se almacenaran los datos correspondientes de desplazamiento, fuerza, tiempo y número de foto. Este ciclo se repetirá completo hasta que el total de pasos sea igual o ligeramente menor a la carrera total del husillo.

En el modo de tracción uniaxial por pasos se define el tamaño del paso y el lapso de tiempo entre cada ciclo de desplazamiento del husillo y adquisición de datos. Luego, durante la ejecución de la prueba, el husillo se desplaza de acuerdo al tamaño del paso ya indicado, se almacenan los datos de desplazamiento, fuerza, tiempo y número de foto

3. RESULTADOS

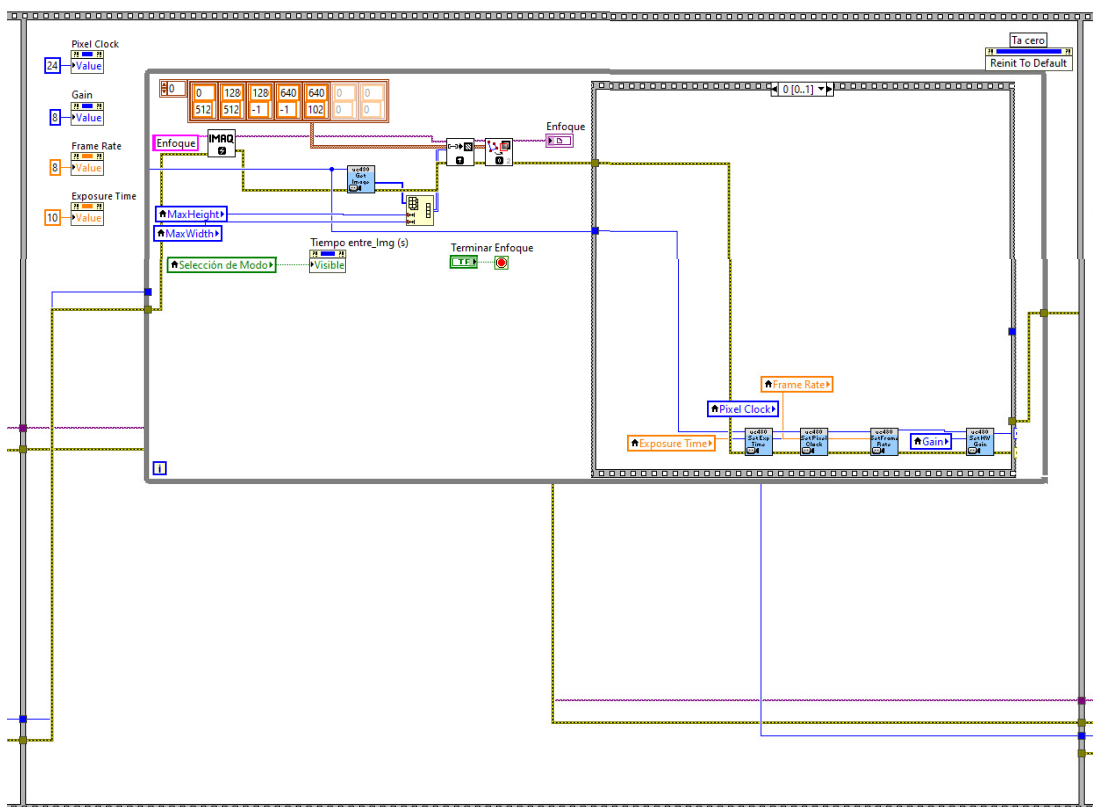


Figura 3.4: La segunda sección del VI muestra el código que permite el ajuste de parámetros como enfoque de la cámara, tiempo de exposición, ganancia, velocidad de actualización del sensor y número de cuadros previo a la prueba.

y luego de la pausa indicada en el tiempo entre cada imagen se repite el proceso hasta alcanzar la posición máxima o más cercana a la permitida por la carrera del husillo del actuador.

El tiempo entre pasos es muy importante; este no debe ser mayor o igual que el tiempo de relajación del material ensayado, pues afectaría los resultados obtenidos. Para nuestro caso, el tiempo de relajación registrado para el pericardio es menor a 30[s] pudiendo variar de acuerdo al contenido y orientación de las fibras de colágeno en las muestras. Este modo nos permite definir intervalos de tiempo muy grandes permitiendo que se comporte de manera similar a una prueba de relajación.

En ambos modos, los datos adquiridos se registran en un archivo de datos con un formato por columnas que permite identificarlos fácilmente. En él, se asocian los valores registrados por los sensores de desplazamiento, fuerza, y el número de la imagen adquirida; todos estos datos se asocian al tiempo registrado por el cronómetro del experimento. Así podemos obtener la correspondencia adecuada entre datos e imágenes de una manera síncrona.

Es importante mencionar que en esta etapa del VI, se aplican los modelos matemáticos obtenidos de las curvas de calibración para cada sensor. Las curvas de calibración se mostrarán mas adelante. Una vez obtenidos los modelos matemáticos, se anexan al código para mapear la salida de voltaje de los sensores a lecturas de desplazamiento o fuerza según sea el caso. Esto permite obtener los datos de fuerza *vs* desplazamiento que se almacenarán para un análisis posterior en Mathematica. En caso de ser necesario en esta etapa aún es posible hacer ajustes de los parámetros de la cámara (enfoque/iluminación) sin afectar o detener la prueba en caso de ser necesario.

3.2.4. Reinicio del actuador, limpieza y finalización de las tareas.

En la última sección del VI, ya que se alcanzaron los parámetros del modo de ejecución elegido, se lleva el actuador a la posición inicial y se alista el montaje para otra prueba; subsecuentemente, se cierra la comunicación con la cámara, se realiza una limpieza de tareas y variables. Esto último es necesario para evitar conflictos de comunicación que alteren o impidan realizar otro ensayo.

3.3. Panel frontal

Hasta este punto se ha explicado el funcionamiento de cada etapa del VI a partir del diagrama de bloques. En LabVIEW el instrumento virtual esta conformado por dos

3. RESULTADOS

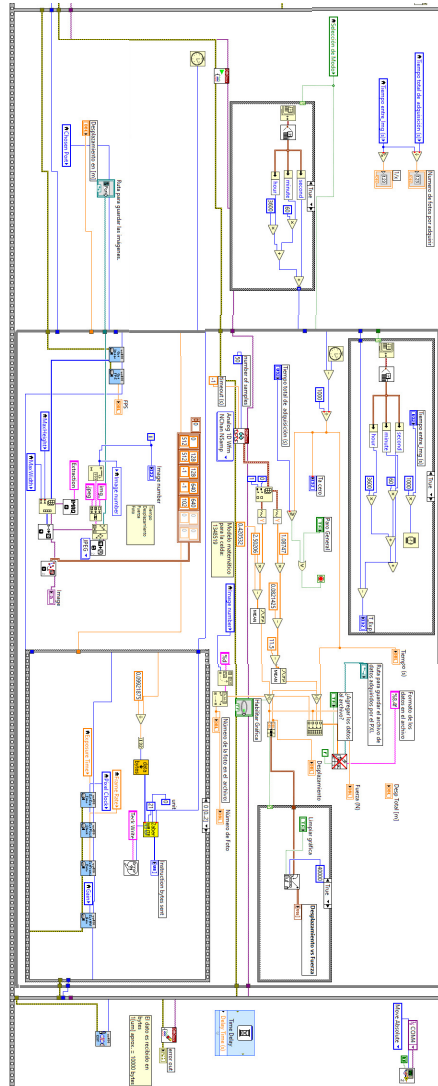


Figura 3.5: La tercera sección del VI contiene el código que permite la adquisición de datos, la aplicación de los modelos matemáticos obtenidos y la gráfica generada a partir de estos..

elementos que representan el cableado interno de un aparato y un panel de controles respectivamente. Para el usuario, se genera un panel frontal Fig. 3.6 en el que aparecen los controles. Estos controles que simulan perillas, botones, interruptores, controles deslizables, etc. deben permitir el manejo simple e intuitivo. Aparecen también ventanas que contienen información obtenida, cuadros de diálogo e imágenes capturadas en tiempo real del experimento. Este panel puede ser dividido en tres columnas considerando las funciones realizadas y la información mostrada en pantalla (ver imagen 3.6).

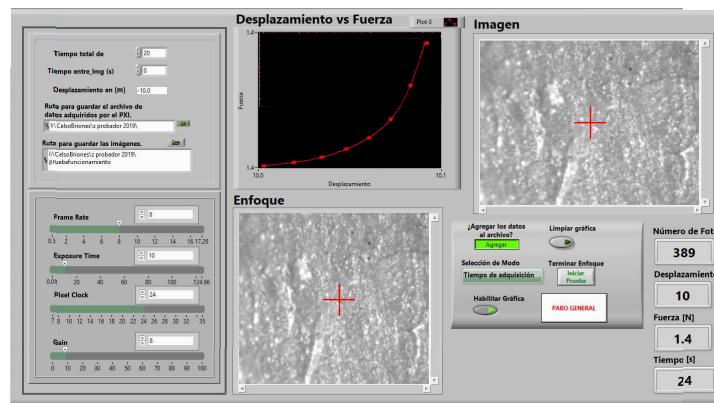


Figura 3.6: El panel frontal muestra los controles, imágenes, gráfica y datos más importantes del experimento.

3.3.1. Parámetros configurables del experimento.

En la columna de la izquierda, en la parte superior, se encuentran los parámetros configurables de la prueba: el tiempo total de adquisición, el tiempo entre imágenes, el desplazamiento en $[\mu\text{m}]$, una ruta para almacenamiento de datos y otra para las imágenes; la asignación de valores para las variables de tiempo y desplazamiento tienen cierto rango que no debe excederse para la realización correcta del ensayo de tracción, es decir, sabemos que el desplazamiento máximo del actuador Zaber es de $18200[\mu\text{m}]$ ó $18.2[\text{mm}]$ con una repetibilidad menor a $4[\mu\text{m}]$, además, de la curva de calibración del LVDT obtuvimos una desviación estándar de $\pm 58[\mu\text{m}]$ ó $\pm 0.058[\text{mm}]$, con lo que podemos asegurar la precisión y exactitud en pasos desde $100[\mu\text{m}]$ ó $0.1[\text{mm}]$ en adelante, permitiendo realizar hasta 182 pasos por prueba como máximo.

3. RESULTADOS

$$\text{Número de pasos} = \frac{18200[\mu m]}{\text{Tamaño de paso}[\mu m]}$$

Por otro lado, las variables de tiempo total de experimentación y tiempo entre imágenes deben de relacionarse con el tamaño del paso y desplazamiento, para mantenerse dentro del rango ya mencionado.

$$\frac{\text{Tiempo total de experimentación}[s]}{\text{Tiempo entre imágenes}[s]} = \frac{18200[\mu m]}{\text{Tamaño de paso}[\mu m]}$$

Finalmente, en la parte inferior, encontramos las barras de control para los ajustes requeridos en el enfoque de la cámara. A diferencia de los parámetros de la prueba que no se pueden modificar después de iniciar, estos pueden ajustarse libremente durante la ejecución Fig. 3.7.

- **Pixel Clock:** (Reloj de píxeles) Este parámetro determina la velocidad a la cual son leídas las celdas del sensor. Un valor muy alto puede causar retrasos o errores de transmisión, el valor máximo de esta variable es de 43[MHz] en resolución completa.
- **Frame Rate:** (Cuadros por segundo) El rango de valores para esta variable depende del valor asignado a la variable reloj de píxeles, con un valor máximo de 24.7 cuadros por segundo con un tiempo de exposición de 1[ms].
- **Exposure Time:** (Tiempo de exposición) Depende del número de cuadros por segundo y es preestablecido como su valor recíproco; un tiempo prolongado de exposición requiere un número reducido de cuadros por segundo y viceversa. Esta variable tiene un rango de 0.009[ms] hasta 2000[ms]
- **Gain:** (Ganancia) Es el voltaje a la salida del sensor que es proporcional a la cantidad de luz incidente, permitiendo incrementar el brillo y contraste de una imagen, el valor máximo es de hasta 4x.

3.3.2. Gráfica e imagen en tiempo real

En la columna central tenemos dos recuadros, el superior nos mostrará la gráfica de Desplazamiento *vs* Fuerza correspondiente al ensayo de tracción uniaxial en curso;

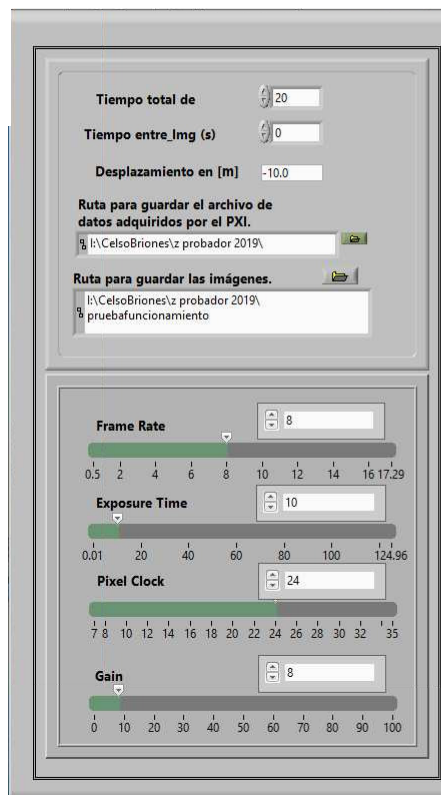


Figura 3.7: La columna izquierda del panel frontal está compuesta por los controles del experimento, las rutas de almacenamiento y los controles de parámetros de la cámara .

3. RESULTADOS

el recuadro de la parte inferior nos permite observar la muestra en tiempo real y de manera continua, permitiendo hacer algún ajuste de enfoque de ser necesario. Fig.3.8.

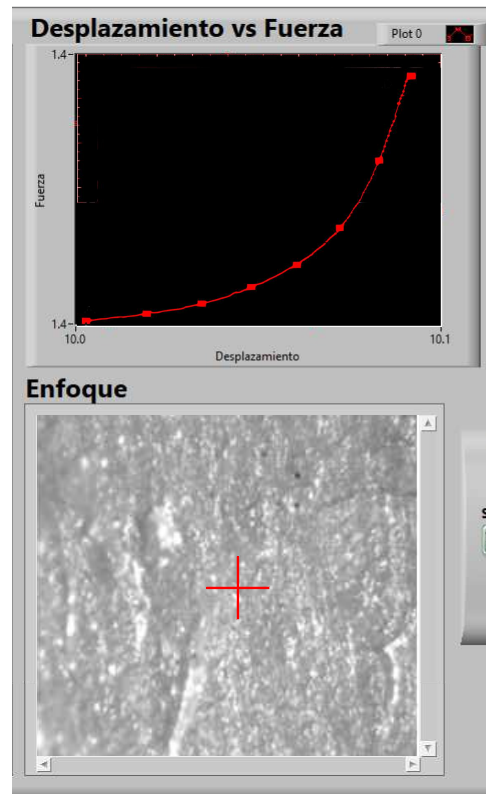


Figura 3.8: En la columna central del panel de control se encuentran la gráfica generada a partir de los datos adquiridos y procesados e imagen de la muestra en tiempo real.

3.3.3. Información adquirida y paro de emergencia

Finalmente en la esquina superior derecha tenemos un recuadro en el que se mostrarán las imágenes adquiridas durante el experimento y en la parte de abajo tenemos los botones de selección de modo de prueba, almacenamiento de datos, término de la etapa de enfoque, habilitación de gráfica, inicio de prueba y paro general.

Las funciones de estos botones pueden parecer redundantes; sin embargo, durante la etapa de desarrollo se encontró que la posibilidad de crear un archivo nuevo o agregar

datos a un archivo existente. Lo anterior puede ser muy útil cuando se ensaya un material repetidas veces. Cabe mencionar que el botón de paro general es sólo una medida de seguridad adicional.

Por último, en la esquina inferior derecha tenemos los indicadores de número de foto, desplazamiento, fuerza y tiempo. Estos datos quedaran registrados y guardados en un archivo de texto. Se logró que el manejo del VI desde el panel frontal permita un manejo sencillo, tanto para la configuración del experimento como para la visualización de los datos e imágenes en tiempo real durante el curso del ensayo, como se aprecia en la Fig. 3.9.



Figura 3.9: La columna derecha del panel frontal muestra la imagen capturada, datos del experimento como número de foto, desplazamiento, fuerza y tiempo, botones para almacenar datos, limpiar la gráfica y paro de emergencia.

El montaje resultante del sistema optomecánico y una vista esquemática del mismo se pueden observar en la Fig. 3.1; en el inciso a) de la figura se indica la disposición

de cada uno de los elementos ya descritos, mientras que en la parte inferior se puede observar el aspecto real del aparato y el tamaño del campo de visión de la imagen adquirida.

3.4. Caracterización de dispositivos.

A continuación se muestran los resultados correspondientes a la calibración de los dispositivos que integran el sistema opto-mecánico y el experimento de tracción uniaxial realizado con una muestra de pericardio bovino.

3.4.1. Modelo de la celda de carga.

Se muestra la curva de calibración obtenida para la celda de carga, los valores se obtuvieron mediante las mediciones de las respuestas obtenidas en varios ciclos de carga y descarga con distintas masas conocidas. El valor de cada masa fue comprobada en una balanza digital Mettler Toledo PM4000. Los datos fueron analizados con el software Mathematica; de este análisis se observa que la calibración presentó una desviación estándar de 0.0068 [N] como se muestra en la Fig. 3.10

3.4.2. Modelo del LVDT.

La calibración del LVDT MRH1000 se llevó a cabo utilizando el actuador Zaber como herramienta de posicionamiento; de manera simultánea el desplazamiento fue comprobado mediante un indicador de desplazamiento de la marca Mitutoyo. Se tomaron lecturas en intervalos de desplazamiento de 100 [μm]. Los datos obtenidos se analizaron en Mathematica para obtener la curva de calibración que se muestra en la Fig. 3.11 Esta curva característica para el rango de ± 10 [mm] muestra una desviación estándar de ± 58 [μm].

3.5. Prueba de tracción uniaxial en pericardio bovino.

Después de la caracterización de los componentes, se realizaron pruebas de tracción uniaxial en muestras de pericardio bovino en forma de hueso de perro (dogbone) que es una forma estándar para este tipo de pruebas. Las probetas fueron preparadas en

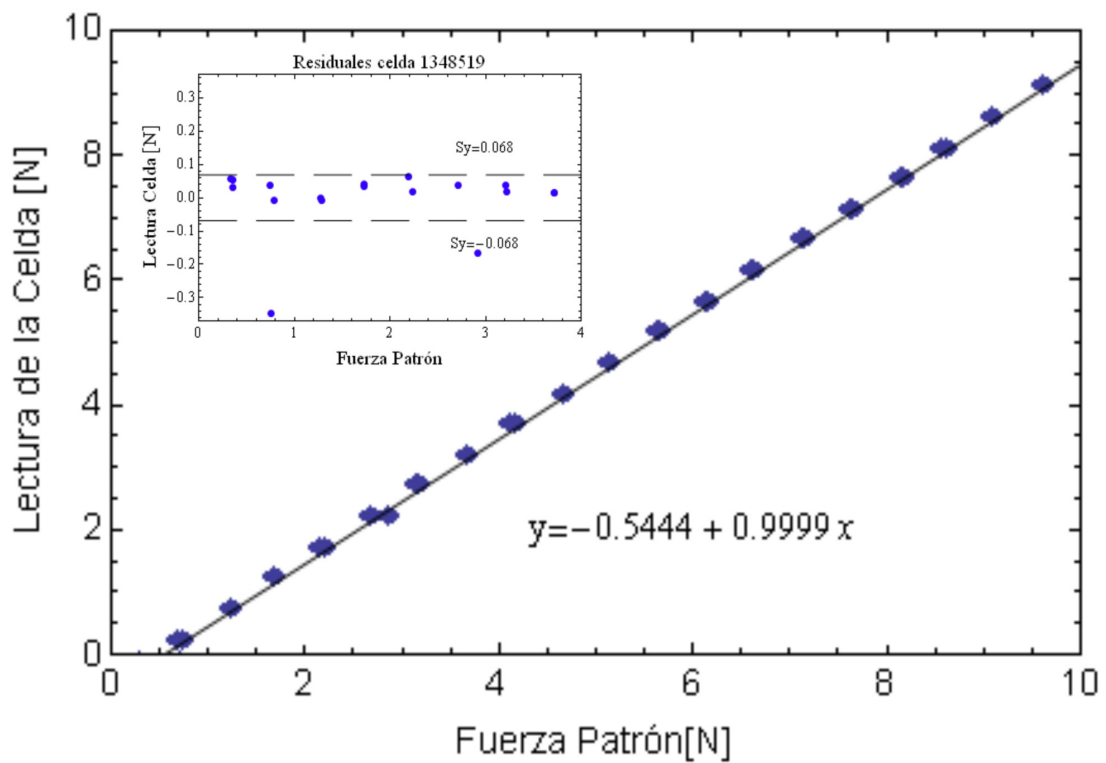


Figura 3.10: Gráfica, modelo matemático y gráfica de residuales obtenidos de la celda de carga

3. RESULTADOS

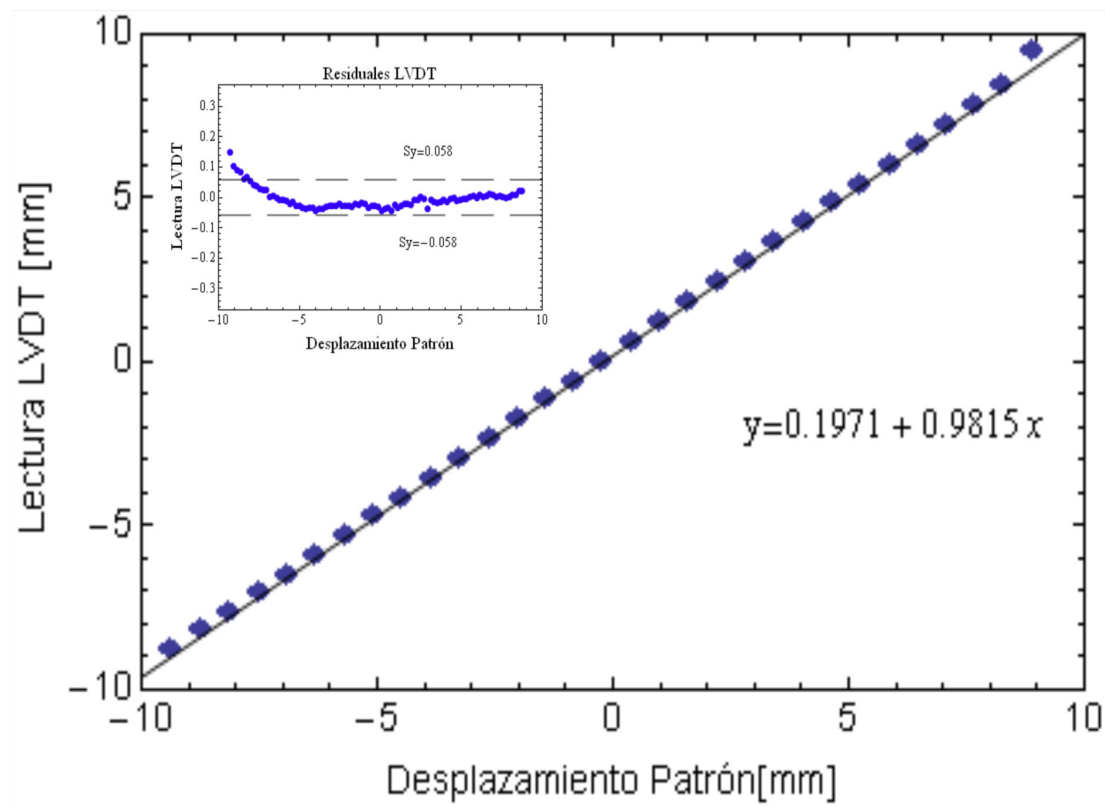


Figura 3.11: Gráfica, modelo matemático y gráfica de residuos obtenidos de la caracterización del LVDT

una solución de glutaraldehído ($C_5H_8O_2$) al 0.5 %, glicerina ($C_3H_8O_3$) y solución salina (NaCl) al 0.9 %. El glutaraldehído es una sustancia que funciona como entrecruzante en las fibras de colágeno del tejido mejorando sus propiedades mecánicas; la Rodamina 6G es un fluoróforo natural que al ser estimulado, con cierta longitud de onda (532 nm), emite luz en un característico tono anaranjado entre los 570 y 600 nm. Al analizar los resultados obtenidos en las pruebas se determinaron los valores de módulo de corte y módulo de Young congruentes con estudios anteriores reportados en la literatura [15, 16].

De la prueba de tracción uniaxial realizada al pericardio bovino, previamente preparado, se obtuvo una curva de Esfuerzo *vs* Razón de elongación en la que se puede observar 3 secciones importantes, identificadas en la Fig. 3.12. La secciones están comprendidas en los segmentos A-B, B-C, y C-D; siendo el punto A el estado inicial de la muestra; es decir, sin tracción, ni deformación. El segmento A-B muestra la respuesta del material al ir alineándose las fibras en el sentido de aplicación de la carga; la sección B-C muestra un incremento en la tracción en proporción al desplazamiento pues una porción considerable de las fibras ya se encuentran alineadas y ofrecen así, mayor resistencia a la deformación. En la región C-D encontramos el mayor incremento del esfuerzo debido a que las fibras se encuentran ya completamente alineadas en el sentido de la aplicación de la carga. En este punto podemos llegar a observar algunas caídas repentinas en la gráfica debido al rompimiento de algunas fibras hasta llegar al punto D que es el esfuerzo máximo al que puede ser sometido el material, luego del cual empieza a decaer debido al rompimiento de las fibras.

3.5.1. Análisis por correlación de imágenes digitales.

De manera simultánea, con las imágenes capturadas y procesadas mediante correlación de imágenes digitales (DIC, por sus siglas en inglés), se obtuvieron campos de desplazamiento que permitieron observar el comportamiento mecánico de las fibras del pericardio a un nivel microscópico durante la prueba de tracción uniaxial.

Las imágenes obtenidas durante la prueba de tracción se analizaron mediante un programa de correlación de imágenes digitales llamado FlowManager de Dantec Dynamics. Dicho programa está basado en el algoritmo reportado por Willert y Gharib en 1991 [20]. Así, conociendo los campos de desplazamiento de manera independiente a los datos macroscópicos, se pueden calcular algunas de las propiedades elásticas promedio del pericardio. La deformación en el plano de deformación (x,y) fue determinada mediante un modelo matemático de seis parámetros previamente reportado en la literatura [15, 16]. Dicho modelo se muestra en las ecuaciones 3.1 y 3.2.

3. RESULTADOS

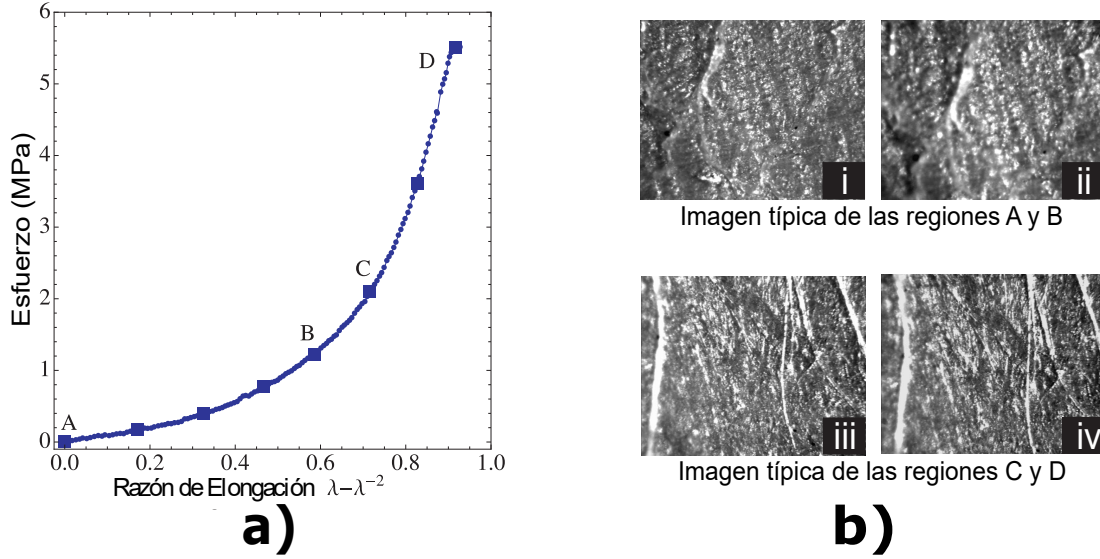


Figura 3.12: a) Curva de Esfuerzo *vs* Elongación, b) Microfotografía de una muestra de pericardio en 4 momentos distintos de una prueba de tracción uniaxial.

$$\mathbf{u}_k(\mathbf{x}_k, \mathbf{y}_k) = \mathbf{A}_1 \mathbf{x}_k + \mathbf{B}_1 \mathbf{y}_k + \mathbf{C}_1 + \delta \mathbf{u}(\mathbf{x}_k, \mathbf{y}_k) \quad (3.1)$$

$$\mathbf{v}_k(\mathbf{x}_k, \mathbf{y}_k) = \mathbf{A}_2 \mathbf{x}_k + \mathbf{B}_2 \mathbf{y}_k + \mathbf{C}_2 + \delta \mathbf{v}(\mathbf{x}_k, \mathbf{y}_k) \quad (3.2)$$

Donde los coeficientes $A_1 = \varepsilon_x$ y $B_2 = \varepsilon_y$ son las deformaciones normales en las direcciones x e y respectivamente; C_1 y C_2 son las traslaciones en las direcciones x e y . La combinación de coeficientes $(A_1 + B_1)/2 = \varepsilon_{xy}$ es el deformación cortante, y la combinación $(A_1 - B_1)/2 = \theta$ es la rotación en el plano xy . Así, $\delta \mathbf{u}(x, y)$ y $\delta \mathbf{v}(x, y)$ son pequeños errores que deben ser minimizados a través de un algoritmo de mínimos cuadrados lineales. Las funciones de minimización están dadas por χ^2 para cada dirección, siendo expresadas como:

$$\chi_{\mathbf{u}}^2 = \sum_{k=1}^n [\mathbf{u}_k - (\mathbf{A}_1 \mathbf{x}_k + \mathbf{B}_1 \mathbf{y}_k + \mathbf{C}_1)]^2 \quad (3.3)$$

$$\chi_v^2 = \sum_{k=1}^n [\mathbf{u}_k - (\mathbf{A}_2 \mathbf{x}_k + \mathbf{B}_2 \mathbf{y}_k + \mathbf{C}_2)]^2 \quad (3.4)$$

Donde n es el número total de objetos o regiones de interés en las que subdividen las imágenes a correlacionar. Al resolver estas ecuaciones, usando ajuste por mínimos cuadrados, las deformaciones en el plano fueron calculadas para diferentes puntos de la curva esfuerzo vs razón de elongación a un nivel micromecánico; concretamente, se presenta dicho análisis para dos regiones comprendidas entre los puntos A-B y C-D, como se muestran en la Figura 3.12. Mientras que el análisis macromecánico, se obtiene del cálculo de las pendientes, en las mismas regiones A-B y C-D, de la curva esfuerzo vs razón de elongación antes mencionada.

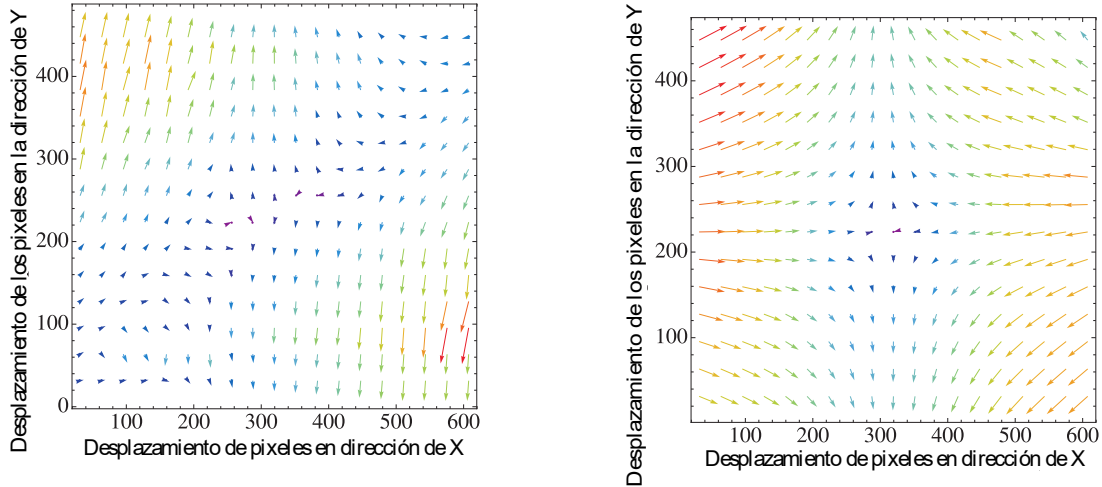


Figura 3.13: Campos de desplazamiento durante una prueba de tracción uniaxial. Acorde al avance de la prueba y la gradual alineación de las fibras en la muestra, podemos ver como los vectores tienden a formar un campo hiperbólico.

3.5.2. Comportamiento macro y micro-mecánico del pericardio bovino

Los resultados obtenidos permitieron establecer una comparación entre los valores de los módulos de corte (G) y el módulo de Young ($3G$) a nivel macro y micromecánico. A nivel macromecánico, se utilizó la gráfica de esfuerzo *vs* razón de elongación y

3. RESULTADOS

se consideraron dos regiones cuyas pendientes son considerablemente diferentes. Esta diferencia en las pendientes se debe al reordenamiento de las fibras de colágeno del pericardio; es importante señalar que este comportamiento es distinto en cada región A-B; en la primera, las fibras están enrolladas y compactas; ofreciendo mínima resistencia a la tracción. En la segunda región C-D la gran mayoría de las fibras ya se encuentran desenrolladas y alineadas respecto a la dirección de la carga aplicada. Lo anterior resulta en incrementos significativos en el valor de esfuerzo normal [3].

En la Figura 3.13 a) se muestran dos campos de desplazamiento asociados a la prueba de tracción uniaxial. El primero corresponde a la región 1 marcada en Figura 3.12 a) entre los puntos A-B. En dicho campo puede apreciarse el proceso de alineamiento de las fibras. Cabe mencionar que la aplicación de la carga se encuentra en el eje vertical; por lo tanto se tiene una elongación en dicha dirección y una contracción en el eje horizontal. El campo mostrado en la Figura 3.13 a) representa la interacción de fibras de colágeno que se deslizan entre sí respecto a la dirección vertical. Por la razón anterior el campo de desplazamiento no es completamente hiperbólico; en lugar se observa un campo equivalente que indica la presencia de deformaciones cortantes. Una vez que se alinean las fibras, el campo de desplazamiento se vuelve hiperbólico como se puede apreciar en la Figura 3.13 b). Es aquí donde se utiliza un proceso de minimización para obtener los valores en deformación asociados a este campo, como se describió anteriormente en las ecuaciones 3.3 y 3.4. Las deformaciones calculadas para la región C-D de este campo fueron $\Delta\epsilon_x=0.007312$, $\Delta\sigma_x=0.89$ MPa; por lo tanto la pendiente en dicha región tendría un valor de 122 MPa.

De acuerdo a la respuesta mecánica que presentó el PB, la cual fue similar a la de los elastómeros; fue posible aplicar el modelo de Neo-Hooke para determinar el módulo elástico del material a nivel macromecánico. Tomando en cuenta dicha consideración, el módulo de corte G está definido como la pendiente de la curva esfuerzo *vs* razón de elongación $\lambda - \lambda^{-2}$. Dado que los materiales elastoméricos presentan una razón de Poisson $\nu=0.5$; el módulo de Young se puede calcular mediante $E = 3G$ [15]. El módulo de corte que se obtuvo para el PB fue de 38 MPa; por lo tanto el módulo de Young fue de 114 MPa a nivel macromecánico. El análisis a nivel micromecánico reveló una pequeña diferencia en dicha propiedad. Dicho módulo a nivel micromecánico fue de 122 MPa. Cuando se trata de analizar la respuesta mecánica de regiones pequeñas, como las valvas en las prótesis cardíacas, se recomienda realizar un estudio a nivel micromecánico con la finalidad de entender de mejor manera la respuesta mecánica del Pericardio bovino y así evitar la falla del material o del dispositivo.

Conclusiones

Se obtuvo un sistema integral para la caracterización macro y micromecánica de materiales suaves y tejido biológico frecuentemente utilizados en aplicaciones biológicas y médicas. Dicho dispositivo permitió evaluar ambos comportamientos de manera simultánea permitiendo la visualización de las fibras de colágeno del pericardio bovino y su interacción durante una prueba de tracción uniaxial. Los resultados obtenidos por este nuevo sistema concuerdan con los reportados previamente en la literatura para el pericardio bovino. Cabe mencionar que el presente dispositivo se convirtió en un desarrollo tecnológico y cubrió la necesidad existente al evaluar la respuesta macro y micromecánica de otro tipo de elastómeros e incluso de elastómeros nanocompuestos.

En cuanto a la correlación digital de imágenes, se demostró que es una herramienta útil para determinar el comportamiento mecánico bajo tensión uniaxial del pericardio bovino liofilizado tratado con glutaraldehído. Con el presente análisis se logró un mejor entendimiento de la respuesta mecánica del pericardio bovino y el efecto del glutaraldehído en su respuesta mecánica. Los campos vectoriales de desplazamiento evidenciaron cambios significativos en la respuesta de las fibras, cuando éstas son tensionadas en una dirección preferencial. También se logró observar que cuando el comportamiento macromecánico se vuelve lineal, los campos de desplazamiento corresponden a los de un material homogéneo y por lo tanto se observó un campo hiperbólico. Esta homogeneidad se perdió cuando las fibras de colágeno comenzaron a romperse, debilitando la estructura del pericardio y produciendo que las fibras de colágeno se deslicen entre sí. Lo anterior se traduce en deformaciones de corte que también fueron detectadas por el análisis de imágenes.

Conocer el comportamiento micromecánico de este biomaterial es útil para aplicaciones médicas en las que un estudio local del tejido es requerido. Las propiedades micromecánicas del pericardio bovino pueden experimentar cambios locales cuando se lleva a cabo algún proceso fisiológico (tal como calcificación o degradación local del te-

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jido). En estos casos, las pruebas macromecánicas convencionales no ofrecen una buena opción para estudiar dichos fenómenos; en su lugar, debe ser realizado un análisis mas detallado. El uso de la correlación digital de imágenes para medir las deformaciones en el plano, ofrece una buena alternativa para explicar los efectos micromecánicos en el comportamiento elástico macroscópico de los elastómeros y tejidos biológicos.

Apéndice A

Celda de Carga.

Model 31 Mid

Mid Range Precision Miniature Load Cell



DESCRIPTION

Model 31 mid range precision miniature load cells measure both tension and compression load forces of 1000 g to 1000 lb. These models are our highest accuracy, rugged miniature load cells. Model 31's welded, stainless steel construction is designed to eliminate or reduce to a minimum, the effects of off-axis loads. (The internal construction assures excellent long-term stability for ranges 1000 grams and above.) A modification permits this model to be completely welded for underwater applications.

The Model 31 tension/compression load cell has male threads attachments. High accuracies of 0.15 % to 0.25 % full scale are achieved. Each bonded strain gage unit is built of welded 17-4 PH stainless steel for additional ruggedness. All load cells with ranges from 1 kg to 10 lb have an electrical balance module in the lead wire (approximately 1 in x .087 in thick). This balance module does not have to be the same temperature as the transducer.

FEATURES

- 1000 g to 1000 lb
- mV/V output
- Stainless steel
- Miniature design

Model 31 Mid

PERFORMANCE SPECIFICATIONS

| Characteristic | Measure |
|-------------------------------------|--|
| Load ranges ⁶ | 1000 g, 5 lb, 10 lb, 25 lb, 50 lb, 100 lb, 250 lb, 500 lb, 1000 lb |
| Linearity 1000 g to 250 lb | ±0.15 % full scale |
| Linearity 500 lb to 1000 lb | ±0.2 % full scale |
| Hysteresis 1000 g to 250 lb | ±0.15 % full scale |
| Hysteresis 500 lb to 1000 lb | ±0.2 % full scale |
| Non-repeatability 1000 g | ±0.1 % full scale |
| Non-repeatability 5 lb to 1000 lb | ±0.05 % full scale |
| Tolerance on output 1000 g | 1.5 mV/V (nominal) |
| Tolerance on output 5 lb to 1000 lb | 2 mV/V |
| Operation | Tension/compression ³ |
| Resolution | Infinite |

ENVIRONMENTAL SPECIFICATIONS

| Characteristic | Measure |
|--------------------------|--------------------------------------|
| Temperature, operating | -53 °C to 121 °C [-65 °F to 250 °F] |
| Temperature, compensated | 15 °C to 71 °C [60 °F to 160 °F] |
| Storage temperature | -73 °C to 148 °C [-100 °F to 300 °F] |
| Temperature effect, zero | 0.005 % full scale/°F |
| Temperature effect, span | 0.005 % full scale/°F |

ELECTRICAL SPECIFICATIONS

| Characteristic | Measure |
|---|--------------------------------|
| Strain gage type | Bonded foil |
| Excitation (calibration) 1 kg to 10 lb | 5 Vdc |
| Excitation (calibration) 25 lb to 1000 lb | 10 Vdc |
| Insulation resistance | 5000 Mohm @ 50 Vdc |
| Bridge resistance | 350 ohm |
| Zero balance | 1 % max. |
| Electrical termination (std) | Teflon cable (1524 mm [60 in]) |

MECHANICAL SPECIFICATIONS

| Characteristic | Measure |
|------------------------|-------------------------|
| Maximum allowable load | 150 % FS ¹ |
| Weight | See table |
| Material | 17-4 PH stainless steel |
| Deflection full scale | See table |
| Natural frequency | See table |

RANGE CODES

| Range codes | Range |
|-------------|---------|
| AR | 1000 g |
| AT | 5 lb |
| AV | 10 lb |
| BL | 25 lb |
| BN | 50 lb |
| BR | 100 lb |
| CN | 250 lb |
| CR | 500 lb |
| CV | 1000 lb |

WIRING CODES

| Cable | Unamplified |
|--------------|----------------|
| Red | (+) excitation |
| Black | (-) excitation |
| Green | (-) output |
| White | (+) output |

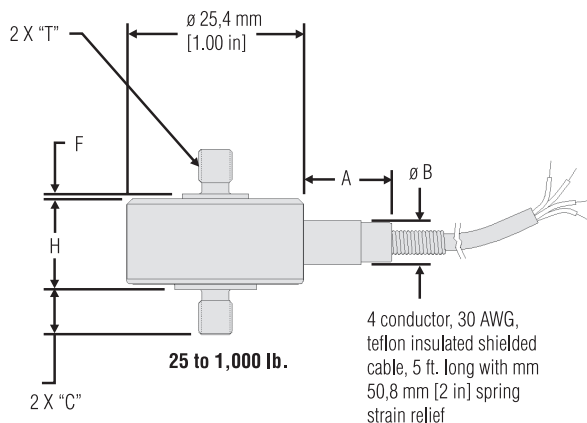
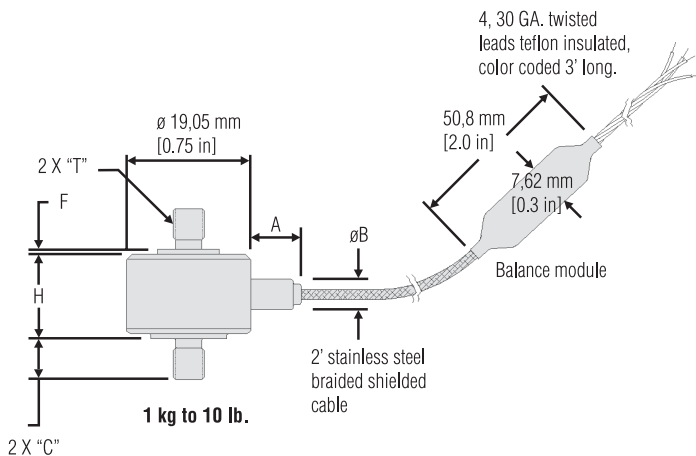
DEFLECTIONS AND RINGING FREQUENCIES

| Capacity (lb) | Deflection at full scale (in) | Ringling frequency (Hz) | Weight (g) |
|-------------------|-------------------------------|-------------------------|------------|
| 1000 g to 10 lb | 0,03 mm [0.001 in] | 3000 Hz | 21 g |
| 25 lb to 100 lb | 0,03 mm [0.001 in] | 10000 Hz | 63 g |
| 250 lb to 1000 lb | 0,04 mm [0.0015 in] | 12000 Hz | 80 g |

Mid Range Precision Miniature Load Cell

MOUNTING DIMENSIONS

| Ranges (lb) | T | H | C | F | A | B |
|-------------------------|------------|-----------------------|----------------------|----------------------|----------------------|----------------------|
| 1000 g, 5 lb, 10 lb | #6-32 UNC | 11,43 mm [0.45 in] | 6,35 mm [0.25 in] | 1,27 mm [0.05 in] | 7,87 mm [0.31 in] | 4,83 mm [0.19 in] |
| 25 lb, 50 lb, 100 lb | #10-32 UNF | 13,21 mm [0.52 in] | 6,35 mm [0.25 in] | 0,76 mm [0.03 in] | 12,7 mm [0.50 in] | 6,35 mm [0.25 in] |
| 250 lb, 500 lb, 1000 lb | 1/4-28 UNF | 13,21 mm [0.52 in] | 9,65 mm [0.38 in] | 0,76 mm [0.03 in] | 12,7 mm [0.50 in] | 6,35 mm [0.25 in] |



OPTION CODES

| | Many range/option combinations are available in our quick-ship and fast-track manufacture programs. Please see http://sensing.honeywell.com/TMsensor-ship for updated listings. | |
|---------------------------------|--|--|
| Load range | 1000 g, 5 lb, 10 lb, 25 lb, 50 lb, 100 lb, 250 lb, 500 lb, 1000 lb | |
| Temperature compensation | 1a. 60 °F to 160 °F 1b. 30 °F to 130 °F 1c. 0 °F to 185 °F 1d. -20 °F to 130 °F 1e. -20 °F to 200 °F 1f. 70 °F to 250 °F | 1g. 70 °F to 325 °F 1h. 70 °F to 400 °F 1i. -65 °F to 250 °F 1j. 0 °C to 50 °C 1k. -20 °C to 85 °C 1m. -25 ° to 110 °C |
| Internal amplifiers | 2u. Unamplified, mV/V output | |
| Overload stops | 4a. Overload stops | |
| Electrical termination | 6a. Bendix PTIH-10-6P - 6 pin (max. 250 °F) ⁵ 6d. Microtec DR-4S-4H 4 pin 6e. Integral cable: Teflon 6f. Integral cable: PVC | 6h. Integral cable: Silicone 6i. Integral underwater cable (max. 180 °F) 6v. Phoenix connector on end of cable 15d. Connector on end of cable |
| Special calibration | 9a. 10 point (5 up/5 down) 20 % increments @ 20 °C 9b. 20 point (10 up/10 down) 10 % increments @ 20 °C | |
| Special calibration | 30a. Compression only calibration, positive in compression 30b. Tension and compression calibration, positive in tension 30c. Compression only calibration, negative in compression | |
| Shock and vibration | 44a. Shock and vibration resistance | |
| Interfaces⁴ | 53e. Signature calibration ⁷ 53t. TEDS IEEE 1451.4 module | |

Apéndice B

LVDT.



MHR-V SERIES

Miniature Vented Case, High Temperature AC LVDT

SPECIFICATIONS

- ◆ Vented case for submersed applications
- ◆ Operating pressure up to 10,000 PSI
- ◆ Operating temperature 392°F [200°C]
- ◆ Small size and low mass core
- ◆ High output signal
- ◆ Stroke ranges from ± 0.025 to ± 1 inch
- ◆ AC operation from 2kHz to 20kHz
- ◆ Stainless steel housing
- ◆ Imperial or metric threaded core

The **MHR-V** Series LVDTs are a variant of the legendary MHR Series. The MHR-V is specifically designed for submersion in inert gas, mineral oil, and other non-aggressive oils (consult factory for medium compatibility) under pressures up to 10,000 PSI [700 bars].

With a diameter of just 3/8 inch [9.5mm], the MHR-V Series allow precision measurements in space restrictive installations at temperatures up to 392°F [200°C]. The extremely lightweight core makes the MHR-V an excellent choice for applications where excessive core weight could influence the motion; with less inertia, accurate measurements at higher displacement speeds are easier to achieve. The lightweight core also reduces mechanical stresses and helps preserve the structural integrity of the core actuation assembly.

The high output sensitivity resulting from the close electrical coupling between the coil and core provides ample signal for interfacing with practically all signal conditioners and conditioning circuits. The magnetic stainless steel housing provides electromagnetic and electrostatic shielding.

Available in a variety of stroke ranges from ± 0.025 to ± 1 inch, the MHR-V is compatible with the full line of Measurement Specialties LVDT signal conditioners.

FEATURES

- ◆ Compact size
- ◆ 10,000 PSI equipressure operation
- ◆ 392°F [200°C] continuous operation
- ◆ Lightweight core
- ◆ Stainless steel case
- ◆ Calibration certificate supplied with each unit

APPLICATIONS

- ◆ Immersion applications (oils, inert gasses)
- ◆ Subsea Oil & Gas equipment
- ◆ Down-hole tools and oil drilling equipment
- ◆ Hydrostatic test chambers
- ◆ Hydraulic spool valve feedback
- ◆ Automotive transmission servo testing

PERFORMANCE SPECIFICATIONS

| ELECTRICAL SPECIFICATIONS (common) | | | | | | |
|--|-------------------|---------------|---------------|---------------|--------------|-------------|
| Input voltage | 3 VRMS sine wave | | | | | |
| Input frequency | 2kHz to 20kHz | | | | | |
| Test frequency | 2.5kHz (standard) | | | | | |
| ELECTRICAL SPECIFICATIONS @ 10kHz (recommended operation) | | | | | | |
| Parameter | MHR-V 025 | MHR-V 050 | MHR-V 100 | MHR-V 250 | MHR-V 500 | MHR-V 1000 |
| Stroke range | ±0.025 [±0.64] | ±0.05 [±1.27] | ±0.10 [±2.54] | ±0.25 [±6.35] | ±0.5 [±12.7] | ±1 [±25.4] |
| Sensitivity, V/V/inch [mV/V/mm] | 8.10 [319] | 3.15 [124] | 2.80 [110] | 2.07 [81.5] | 1.96 [77.2] | 0.77 [30.3] |
| Output at stroke ends, mV/V (*) | 202.5 | 157.5 | 280 | 517.5 | 980 | 770 |
| Phase shift | +21° | +8° | +5° | +7° | +7° | -1° |
| Input impedance (PRIMARY) | 238Ω | 419Ω | 400Ω | 345Ω | 264Ω | 155Ω |
| Output impedance (SECONDARY) | 485Ω | 154Ω | 200Ω | 420Ω | 810Ω | 450Ω |
| Non-linearity | ±% of FR | | | | | |
| @ 50% stroke | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.20 |
| @100% stroke (maximum) | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| @125% stroke | 0.25 | 0.35 | 0.25 | 0.35 | 0.30 (**) | 0.50 |
| @150% stroke | 0.30 | 0.50 | 0.30 | 0.50 (**) | 0.75 (**) | / |
| Null voltage (max.) | 0.5% of FSO | | | | | |

| ELECTRICAL SPECIFICATIONS @ 2.5kHz (standard calibration) | | | | | | |
|--|----------------|---------------|---------------|---------------|--------------|-------------|
| Parameter | MHR-V 025 | MHR-V 050 | MHR-V 100 | MHR-V 250 | MHR-V 500 | MHR-V 1000 |
| Stroke range | ±0.025 [±0.64] | ±0.05 [±1.27] | ±0.10 [±2.54] | ±0.25 [±6.35] | ±0.5 [±12.7] | ±1 [±25.4] |
| Sensitivity, V/V/in [mV/V/mm] | 4.36 [172] | 2.55 [100] | 2.40 [94] | 1.73 [68] | 1.60 [63] | 0.70 [27] |
| Output at 100% stroke, mV/V (*) | 109 | 127.5 | 240 | 432.5 | 800 | 700 |
| Phase shift | +58° | +36° | +30° | +33° | +23° | +6° |
| Input impedance (PRIMARY) | 116Ω | 141Ω | 135Ω | 147Ω | 145Ω | 100Ω |
| Output impedance (SECONDARY) | 286Ω | 90Ω | 125Ω | 268Ω | 445Ω | 370Ω |
| Non-linearity | ±% of FR | | | | | |
| @ 50% stroke | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.20 |
| @100% stroke (maximum) | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| @125% stroke | 0.25 | 0.35 | 0.25 | 0.35 | 0.30 (**) | 0.50 |
| @150% stroke | 0.30 | 0.50 | 0.30 | 0.50 (**) | 0.75 (**) | / |
| Null voltage (max) | 0.5% of FSO | | | | | |

| ENVIRONMENTAL SPECIFICATIONS & MATERIALS | |
|---|--|
| Operating temperature | -4°F to +392°F [-20°C to +200°C] |
| Operating pressure | Up to 10,000 PSI [700 bars]; maximum slew rate 1,000 PSI [70 bars] per minute (***) |
| Housing material | AISI 400 Series stainless steel |
| Electrical connection | Six lead-wires, 32 AWG stranded plated Copper, PTFE insulated, 3 foot [1 meter] long |

Notes:

All values are nominal unless otherwise noted

Electrical specifications are for the test frequency indicated in the table

Dimensions are in inch [mm] unless otherwise noted

FR: Full Range is the stroke range, end to end; FR=2xS for ±S stroke range

FSO (Full Scale Output): Largest absolute value of the outputs measured at the ends of the range

(*) Unit for output at stroke ends is millivolt per volt of excitation (input voltage)

(**) Requires special reduced core length

(***) Do not increase or decrease pressure faster than 1,000 PSI [70 bars] per minute to avoid permanent damage

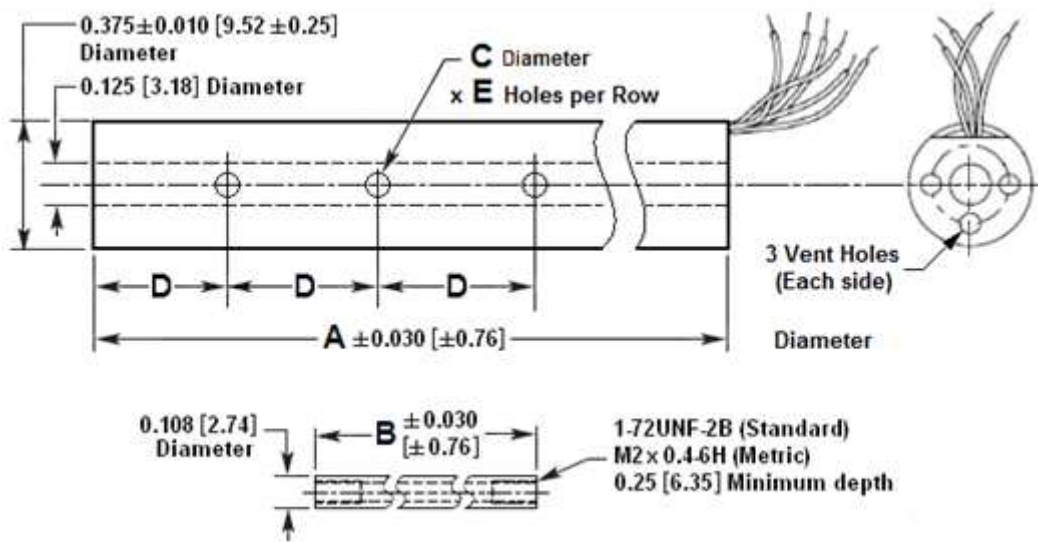


MHR-T SERIES

Miniature High-Temperature AC LVDT

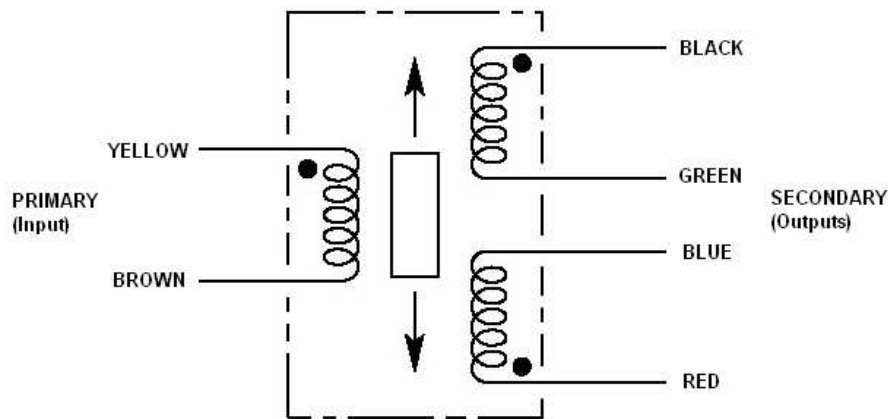
MECHANICAL SPECIFICATIONS

| Parameter | MHR-V 025 | MHR-V 050 | MHR-V 100 | MHR-V 250 | MHR-V 500 | MHR-V 1000 |
|--|-----------------------------|--------------|--------------|--------------|---------------|---------------|
| Body length "A" | 0.660 [16.8] | 0.815 [20.7] | 0.990 [25.1] | 1.850 [47.0] | 3.300 [83.82] | 5.600 [142.2] |
| Core length "B" | 0.400 [10.2] | 0.500 [12.7] | 0.625 [15.9] | 1.125 [28.6] | 2.000 [50.8] | 3.000 [76.2] |
| Housing vent hole diameter "C" | 0.063 [1.60] | 0.063 [1.60] | 0.063 [1.60] | 0.063 [1.60] | 0.063 [1.60] | 0.063 [1.60] |
| Vent hole spacing "D" | 0.20 [5.1] to 0.28 [7.1] | 0.27 [6.9] | 0.33 [8.4] | 0.46 [11.7] | 0.825 [21.0] | 0.80 [20.3] |
| Number of vent holes per row "E" | 2 | 2 | 2 | 3 | 3 | 6 |
| Number of hole rows around housing "F" | 4 | 4 | 4 | 3 | 3 | 3 |
| Body weight, oz [g] | 0.18 [5] | 0.21 [6] | 0.21 [6] | 0.32 [9] | 0.60 [17] | 0.92 [26] |
| Core weight, oz [g] | 0.016 [0.5] | 0.016 [0.5] | 0.025 [0.7] | 0.032 [0.9] | 0.056 [1.6] | 0.088 [2.5] |



Dimensions are in inch [mm]

WIRING INFORMATION



Connect Blue to Green for differential output

MHR-T SERIES

Miniature High-Temperature AC LVDT

ORDERING INFORMATION

| Description | Model | Part Number |
|------------------|-----------|--------------|
| ±0.025 inch LVDT | MHR-V 025 | 02564407-000 |
| ±0.05 inch LVDT | MHR-V 050 | 02564408-000 |
| ±0.10 inch LVDT | MHR-V 100 | 02564409-000 |

| Description | Model | Part Number |
|-----------------|------------|--------------|
| ±0.25 inch LVDT | MHR-V 250 | 02564410-000 |
| ±0.5 inch LVDT | MHR-V 500 | 02564411-000 |
| ±1 inch LVDT | MHR-V 1000 | 02564412-000 |

| OPTIONS AND ACCESSORIES | |
|--|--------------|
| Metric threaded core (use base part numbers from above) | XXXXXXXX-006 |
| Core connecting rod, 6 inches long, 1-72 threads | 05282945-006 |
| Core connecting rod, 12 inches long, 1-72 threads | 05282945-012 |
| Core connecting rod, 24 inches long, 1-72 threads | 05282945-024 |
| Core connecting rod, 36 inches long, 1-72 threads | 05282945-036 |
| Core connecting rod, 6 inches long, M2x0.4 metric threads | 05282976-006 |
| Core connecting rod, 12 inches long, M2x0.4 metric threads | 05282976-012 |

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Actuador mecánico lineal.

T-LA Series User's Manual

Miniature linear actuators with built-in controllers



Zaber's products are not intended for use in any critical medical, aviation, or military applications or situations where a product's use or failure could cause personal injury, death, or damage to property. Zaber disclaims any and all liability for injury or other damages resulting from the use of our products.

Zaber's motion control devices are precision instruments and must be handled with care. In particular, moving parts must be treated with care. Avoid axial loads in excess of the rated thrust load, axial and radial impact, dust and other contaminants and damage to the leadscrew thread. These will reduce the performance of the device below stated specifications.

Special Note

The plunger should always be left in the fully retracted position (home) when not in use.

Lubrication

Performance depends very much on the condition of the leadscrew, so the leadscrew should be cleaned periodically for best results. To clean the screw, first use isopropyl alcohol to dissolve old grease and contaminants. There are plastic components that may be damaged by some strong solvents. Apply a small amount of grease. The grease will reduce friction, backlash and sticktion. We use NyeClean 5077 vacuum grease available from www.nyelubricants.com. A similar grease with a compatible thickener and lubricant are also suitable.

If you are unfamiliar with T-series devices, you may wish to perform a few simple steps to familiarize yourself with their operation. First you will need a power supply. If you did not add one to your order, you will require a power supply that matches the voltage requirement of the device. Some T-series products, usually devices that run on 12 - 16 V, transmit power between devices through the data cables. The chosen power supply must be rated to handle the maximum total current draw of all devices connected to it. When powering long chains of devices, we recommend connecting a power supply to at least every 3rd device in the chain to reduce the current through the data cables. Devices that run on more than 16 V do not transmit power through the data cables.

Once you have a working power supply, you can test the operation of your device. Try turning the potentiometer (if applicable) counterclockwise to home the device. When operating manually, you should home the device by retracting it completely every time you disconnect or turn off the power. You will not be able to achieve the maximum travel until you have homed the device or sent a command to tell the device its current position. After the device retracts completely it will stop automatically and you can turn the potentiometer clockwise to move the device. If you have a model without a potentiometer, you cannot control the device manually. Instead you must connect the device to a computer and issue a home instruction.

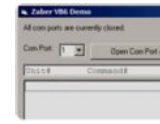
Connection to a Computer

Connect the device to a computer as follows:


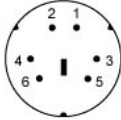
1. Either plug the Mini-DIN to D-Sub serial adaptor (**T-DSUB9**) into your computer's serial port, or the Mini-DIN to USB adapter (**T-USBDC**) into one of your computer's USB ports, then plug the device's data cable into the adaptor. For the USB adaptor, new computers will often be able to install the necessary drivers automatically when the cable is plugged in for the first time. If the computer reports that the driver installation was unsuccessful, you can download the drivers for Windows, Mac, or Linux [here](#). Installation instructions and troubleshooting information are available for each operation system [here](#). You may need to use a cable extension to reach your computer. There is no need to power-down or reboot the computer.
2. Connect the power plug of your power supply to the power connector of the device (figure 2). If present, the green LED should light up indicating the device has power (some devices may not have LEDs).
3. If your device comes with a knob for manually adjusting the actuator's position, set the knob to the neutral position between forward and backward. At this point, you will feel a slight detent and the yellow light (if present) will turn off. For the device to receive computer commands, the manual knob must be in the neutral position.
4. Additional devices can simply be daisy-chained to the first (figure 3). For long chains of devices that daisy chain power, a power supply should be connected at every 2nd or 3rd device. A renumber command needs to be issued after a new device is connected, before it can be controlled independently.
5. Install software from the [software page](#) (figure 4). We recommend installing the Zaber Console to get started. As a simple first test, try entering these instructions:

```
Renumber all devices          - Device: 0, Cmd: 2, Data: 0
Home device 1                 - Device: 1, Cmd: 1, Data: 0
Move device 1 to 10,000 microsteps - Device: 1, Cmd: 20, Data: 10000
```

To see the microstep distance (resolution) for your device, see the specs page for that device on the respective [product page](#).



Data Cable Wiring Diagram

| Pin# | Minidin 6 Female (to next device) | Minidin 6 Male (to previous device) |
|------|---|---|
| |  |  |
| 1 | - | - |
| 2 | Receive (from next device) | Transmit (toward computer) |
| 3 | Ground | Ground |
| 4 | +12-16 Vdc * | +12-16 Vdc * |
| 5 | - | - |
| 6 | Transmit (to next device) | Receive (from computer) |
| nc | - | - |

* T-Series 12-16V devices only (all T-series devices, except **T-LSQ**, **T-LST**, **T-MCA**)

Note that multiple cable suppliers have been used over the years, each implementing different color codes. Rather than relying on the wire colors, it is recommended that users perform a continuity test to determine which wires are connected to which pins on their own device.

To connect a Zaber device to a computer serial port requires a **T-DSUB9** adaptor. It looks similar to an old PS/2 serial mouse adaptor, but it has different wiring.

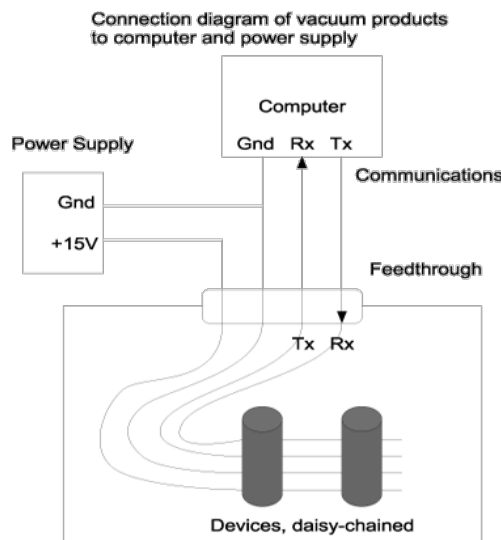
Connecting Vacuum Compatible Devices

These Zaber products are available in a vacuum compatible version. Vacuum compatible devices (identifiable by the suffix "-V" in the part number) have special requirements for their connection to a computer.

Power: No power connectors are provided on vacuum compatible devices. Instead, power must be supplied through the data cable lines. A special serial adaptor with power input is provided.

Data Cables: Vacuum compatible devices use the same mini-din data cable extensions as our standard devices; however, the cable jacket is stripped back to the connectors to expose the individual wires. The mini-din connectors are left attached to facilitate easy testing. In your final application you can cut the wires and splice them to a feed-through on your vacuum chamber. Communication lines can be wired back to the appropriate mini-din connector outside your vacuum chamber. Power lines can be wired to any appropriate power supply. See the table below for pinouts. If you have multiple units inside the same vacuum chamber you may connect them using the attached mini-din connectors, or for improved vacuum compatibility you may remove the connectors and permanently wire the units together.

Grounding: When re-wiring Zaber devices it is important to wire the ground to both the computer and the power supply (see diagram below). Alternately, the T-DSUB9-P vacuum adaptor can be substituted into an order to make this connection.





Physical Installation

Mounting

When mounting a Zaber linear actuator, care must be taken not to over-constrain the leadscrew. At the point of contact between the leadscrew and the object to be moved there are 6 degrees of freedom which can be constrained: translation along xyz axes and rotation about those axes. The load should constrain only the axial translation of the leadscrew. The simplest way to achieve this is to have the lead screw press against a flat surface perpendicular to the axis of the leadscrew. Any further constraint (such as rigidly fixing the leadscrew to the load) may result in an over-constrained system that will reduce thrust or cause the leadscrew to bind.

You can mount the actuator by sliding the 9.5mm mounting shank through the hole on a translation stage (like our TSB stages). Tighten a clamp around the shank or secure the included 3/8-32 screw on the other side of the hole. Some actuators also have mounting holes on the side or bottom of the actuator, and come with mounting screws.

Grounding

To prevent damage to the device due to static buildup, the device should be properly grounded.

Failure to ground the unit may result in the unit shutting down unexpectedly or ceasing to communicate with the computer. This problem can be minimized by not touching the unit during operation. If the unit fails due to static discharge, unplugging it and plugging it back in or sending a Restore Settings command will usually fix the problem.

Most Zaber devices are grounded via the shield wire of the data cables. This should normally provide a path to ground via the computer. For units which are being used without a computer, a ground lead should be connected to the shield of one of the data cables.

The T-LA is particularly sensitive to static discharge at the front mount. For best results, avoid touching the front mount of the T-LA while the device is in operation.

All T-Series devices use the same RS232 communications protocol. Your communications settings must be: 9600 baud, no hand shaking, 8 data bits, no parity, one stop bit. The yellow LED will light when there is activity on the RS232 lines. You may use this feature to determine which COM port you are connected to. We recommend using the [Zaber Console](#) that you can download from our web site. The source code is also available for you to use as an example for writing your own custom code. See the troubleshooting section later in this manual if you have trouble communicating with the device.

Important: The first time you connect a device to your computer you must issue a renumber instruction to assign each device a unique identifier. This should be done after all the devices in the daisy-chain are powered up. In older firmware versions (prior to version 5xx) you must issue a renumber instruction after each powerup. In firmware 5xx and up, the device number is stored in non-volatile memory and will persist after powerdown, so you need only issue the renumber instruction when you add new devices to the chain, or rearrange the order of the devices, however it does no harm to issue the renumber instruction after every powerup. You must not transmit any instructions while the chain is renumbering or the renumbering routine may be corrupted. Renumbering takes less than a second, after which you may start issuing instructions over the RS232 connection.

All instructions consist of a group of 6 bytes. They must be transmitted with less than 10 ms between each byte. If the device has received less than 6 bytes and then a period longer than 10 ms passes, it ignores the bytes already received. We recommend that your software behave similarly when receiving data from the devices, especially in a noisy environment like a pulsed laser lab.

The following table shows the instruction format:

- Byte 1 - Device #
- Byte 2 - Command #
- Byte 3 - Data - Least Significant Byte (LSB)
- Byte 4 - Data
- Byte 5 - Data
- Byte 6 - Data - Most Significant Byte (MSB)

The first byte is the device number in the daisy-chain. Device number 1 is the closest device to the computer and device number 2 is next and so on. If the number 0 is used, all the devices in the chain will process the accompanying command simultaneously.

The second byte is the command number. Bytes 3, 4, 5, and 6 are data in long integer, 2's complement format with the least significant byte transmitted first. How the command data are interpreted depends on the command. Complete details are given in the command reference on the following page.

Examples

- All devices renumber: 0, 2, 0, 0, 0, 0
- All devices home: 0, 1, 0, 0, 0, 0
- All devices return firmware version: 0, 51, 0, 0, 0, 0
- Device 1 move to an absolute position (command 20) of 257 microsteps: 1, 20, 1, 1, 0, 0
- Device 2 move to a relative position (command 21) of -1 microstep: 2, 21, 255, 255, 255, 255

Most instructions cause the device to reply with a return code. It is also a group of 6 bytes. The first byte is the device #. Byte #2 is the instruction just completed or 255 (0xFF) if an error occurs. Bytes 3, 4, 5 and 6 are data bytes in the same format as the instruction command data.

Data Conversion Algorithms

If you are writing software to control Zaber products, you'll likely need to generate data bytes 3 through 6 from a single data value, or vice versa. The following pseudo-code can be used as a model.

Converting command data into command bytes to send to Zaber products

```

If Cmd_Data < 0 then Cmd_Data = 256^4 + Cmd_Data           'Handles negative data

Cmd_Byte_6 = Cmd_Data / 256^3

Cmd_Data = Cmd_Data - 256^3 * Cmd_Byte_6

Cmd_Byte_5 = Cmd_Data / 256^2

Cmd_Data = Cmd_Data - 256^2 * Cmd_Byte_5

Cmd_Byte_4 = Cmd_Data / 256

Cmd_Data = Cmd_Data - 256 * Cmd_Byte_4

Cmd_Byte_3 = Cmd_Data
    
```

Converting reply bytes into a single reply data value

```

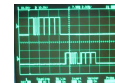
Reply_Data = 256^3 * Rpl_Byte_6 + 256^2 * Rpl_Byte_5 + 256 * Rpl_Byte_4 + Rpl_Byte_3

If Rpl_Byte_6 > 127 then Reply_Data = Reply_Data - 256^4           'Handles negative data
    
```

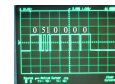
Sample Waveforms

If you are designing hardware to interface with Zaber products, it may be useful to see some sample waveforms.

This image shows an instruction (top waveform) and a reply (bottom waveform).



This is a closeup of the instruction bytes. Note that the voltage swing of the instruction waveform is about +/-10V. This is typical of the USB to RS232 converter to which the device is connected. The instruction bytes are 0, 51, 0, 0, 0, 0 indicating the instruction: Device: All, Command: Return version, Data: 0.



This is a closeup of the instruction byte 2. The "S" on either end represents the start and stop bits respectively. The start bit is always positive and the stop bit is always negative. The bit sequence is Start, 0, 1, 2, 3, 4, 5, 6, 7, Stop. The data is output with the least significant bit first, so the byte shown is actually 00110011 in binary or 32+16+2+1 = 51 in decimal.



It's a good idea to do a timing "reality check" whenever viewing a waveform such as this. The bit rate should be 9600 bits/second. The time scale in the image is 200 us/division. Since a byte consists of 10 bits (start, stop, plus 8 data bits) and the bit rate is 9600 bits/s, the duration of a single byte should be 1.04 ms (10/9600 seconds) or about 5.2 divisions at 200 us/division. It can be seen in the image that this is the case.

This is a closeup of the reply bytes. Note that the voltage swing of the reply waveform is about +/-8V. This is a typical output from the RS232 driver chip used in Zaber devices. The instruction was to all devices. Only a single device is present so there is only one reply. The reply is 1, 51, 252, 1, 0, 0 indicating the reply "Device: 1, Reply: Firmware version, Data: 508". The data is the last 4 bytes combined, with least significant byte first. In this case the data is 0*256^3 + 0*256^2 + 1*256 + 252 = 508. This indicates a firmware version of 5.08 since according to the instruction specification a decimal is assumed before the last two digits.



The time scale in this image is 1 ms/division. As noted above, at a bit rate of 9600 bits/second each byte should take 1.04 ms. Therefore a 6 byte reply should take 6.24 ms. It can be seen in the image that this is the case.

The following table offers a quick command reference for motorized devices running firmware version 5xx. For convenience, you may sort the table below by instruction name, command number, or reply number. Follow the links to view a detailed description of each instruction.

| Instruction Name | Command# | Command Data | Command Type | Reply Data |
|---|----------|-------------------|--------------|---------------------------------|
| Reset | 0 | Ignored | Command | None |
| Home | 1 | Ignored | Command | Final position (in this case 0) |
| ReNUMBER* | 2 | Ignored | Command | Device ID |
| Move Tracking | 8 | n/a | Reply | Tracking Position |
| Limit Active | 9 | n/a | Reply | Final Position |
| Manual Move Tracking | 10 | n/a | Reply | Tracking Position |
| Store Current Position* | 16 | Address | Command | Address |
| Return Stored Position | 17 | Address | Command | Stored Position |
| Move To Stored Position | 18 | Address | Command | Final Position |
| Move Absolute | 20 | Absolute Position | Command | Final Position |
| Move Relative | 21 | Relative Position | Command | Final Position |
| Move At Constant Speed | 22 | Speed | Command | Speed |

| | | | | |
|-----------------------------|-----|----------------|-------------------|----------------|
| Move At Constant Speed | 22 | Speed | Command | Speed |
| Stop | 23 | Ignored | Command | Final Position |
| Read Or Write Memory* | 35 | Data | Command | Data |
| Restore Settings* | 36 | Peripheral ID | Command | Peripheral ID |
| Set Microstep Resolution* | 37 | Microsteps | Setting | Microsteps |
| Set Running Current* | 38 | Value | Setting | Value |
| Set Hold Current* | 39 | Value | Setting | Value |
| Set Device Mode* | 40 | Mode | Setting | Mode |
| Set Home Speed* | 41 | Speed | Setting | Speed |
| Set Target Speed* | 42 | Speed | Setting | Speed |
| Set Acceleration* | 43 | Acceleration | Setting | Acceleration |
| Set Maximum Position* | 44 | Range | Setting | Range |
| Set Current Position | 45 | New Position | Setting | New Position |
| Set Maximum Relative Move* | 46 | Range | Setting | Range |
| Set Home Offset* | 47 | Offset | Setting | Offset |
| Set Alias Number* | 48 | Alias Number | Setting | Alias Number |
| Set Lock State* | 49 | Lock Status | Command | Lock Status |
| Return Device ID | 50 | Ignored | Read-Only Setting | Device ID |
| Return Firmware Version | 51 | Ignored | Read-Only Setting | Version |
| Return Power Supply Voltage | 52 | Ignored | Read-Only Setting | Voltage |
| Return Setting | 53 | Setting Number | Command | Setting Value |
| Return Status | 54 | Ignored | Read-Only Setting | Status |
| Echo Data | 55 | Data | Command | Data |
| Return Current Position | 60 | Ignored | Read-Only Setting | Position |
| Return Serial Number | 63 | Ignored | Read-Only Setting | Serial Number |
| Error | 255 | n/a | Reply | Error Code |

* The settings for these commands are saved in non-volatile memory, i.e. the setting persists even if the device is powered down. To restore all settings to factory default, use command 36.

This command reference applies only to firmware version 5.00 and up to the most recent version. The version of firmware installed on any Zaber T-Series device can be determined by issuing **command #51**. A three-digit number will be returned. Assume 2 decimal places (ex a reply of 293 indicates firmware version 2.93). For earlier versions of firmware, please consult the appropriate PDF user's manual:

T-Series Manual 2xx ([PDF](#))

T-Series Manual 4xx ([PDF](#))

Due to the addition of new features, newer versions of firmware may not be 100% backward compatible. You may wish to read the document [Firmware History and Migration](#) which outlines the changes that have taken place from one firmware version to the next and indicates what options are available if you wish to upgrade or downgrade the firmware on your devices.

Reset - Cmd 0

| | |
|----------------------------------|--|
| Instruction Name | Reset |
| Applies to | All Zaber devices |
| Firmware Version | 5.00 and up |
| Command Number | 0 |
| Command Type | Command |
| Command Data | Ignored |
| Reply Data | None |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Sets the device to its power-up condition. |

This has the same effect as unplugging and restarting the device.

Special Note

The position stored in the device prior to this command will be lost, so you must save it and reload it if it is important. All non-volatile settings (i.e. Device Number, Target Velocity, etc.) are saved and are not affected by reset or power-down.

Home - Cmd 1

| | |
|----------------------------------|---|
| Instruction Name | Home |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 1 |
| Command Type | Command |
| Command Data | Ignored |
| Reply Data | Final Position |
| Safe to retry? | Yes |
| Returns Current Position? | Yes |
| Persistence | n/a |
| Summary | Moves to the home position and resets the device's internal position. |

Upon receiving this instruction, the device will retract until its internal home sensor is triggered. It will then move forward several steps to avoid accidentally re-triggering the home sensor during use. Its internal position is then reset (to 0 for most devices). If a home offset has been specified with the [Set Home Offset \(cmd 47\)](#) instruction, the device will move forward for the specific offset, then reset the internal position.

Prior to Firmware 5.21, the device will attempt to home for an extended amount of time. For Firmware 5.21 and up, the home command aborts with an error if the device has traveled twice the Maximum Position setting without triggering the home sensor. This indicates that the device could possibly be stalling or slipping.

Renumber - Cmd 2

| | |
|----------------------------------|--|
| Instruction Name | Renumber |
| Applies to | All Zaber devices |
| Firmware Version | 5.00 and up |
| Command Number | 2 |
| Command Type | Command |
| Command Data | New Number |
| Reply Data | Device ID |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Assigns new numbers to all the devices in the order in which they are connected. |

This command is usually sent to device number 0. When it is, the command data is ignored and all devices will renumber. The device closest to the computer becomes device number 1. The next device becomes number 2 and so on.

If sent to a device number other than 0, then that device will reassign itself the device number in the command data. Valid device numbers are 1-99 for version 6.05, and 1-254 otherwise.

Note: Renumbering takes about 1/2 a second during which time the computer must not send any further data. The device number is stored in non-volatile memory so you can renumber once and not worry about issuing the renumber instruction again after each power-up.

Store Current Position - Cmd 16

| | |
|-------------------------|------------------------|
| Instruction Name | Store Current Position |
| Applies to | All motorized devices |
| Firmware Version | 5.04 and up |
| Command Number | 16 |
| Command Type | Command |
| Command Data | Address |

| | |
|----------------------------------|--|
| Reply Data | Address |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Saves the current absolute position of the device. |

Valid Address values are 0 through 15 specifying one of 16 possible registers in which to store the position. This command can only be executed when the device has been homed. This command is used in conjunction with the [Return Stored Position \(Command #17\)](#) and [Move To Stored Position \(Command #18\)](#) instructions. The positions stored in the position registers are non-volatile and will persist after power-down or reset. All position registers are cleared by the [Restore Settings \(Command #36\)](#) instruction.

Return Stored Position - Cmd 17

| | |
|----------------------------------|---|
| Instruction Name | Return Stored Position |
| Applies to | All motorized devices |
| Firmware Version | 5.04 and up |
| Command Number | 17 |
| Command Type | Command |
| Command Data | Address |
| Reply Data | Stored Position |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Returns the position stored in one of the 16 position registers for the device. |

Valid command data values are 0 through 15, specifying one of 16 possible registers from which to retrieve the position. This command is used in conjunction with the [Store Current Position \(#16\)](#) and [Move To Stored Position \(#18\)](#) commands. Positions stored in the position registers are non-volatile and will persist after power-down or reset. All position registers are cleared by the [Restore Settings \(#36\)](#) command.

Move To Stored Position - Cmd 18

| | |
|----------------------------------|--|
| Instruction Name | Move To Stored Position |
| Applies to | All motorized devices |
| Firmware Version | 5.04 and up |
| Command Number | 18 |
| Command Type | Command |
| Command Data | Address |
| Reply Data | Final Position |
| Safe to retry? | Yes |
| Returns Current Position? | Yes |
| Persistence | n/a |
| Summary | Moves the device to the stored position specified by the Command Data. |

Valid address values are 0 through 15, specifying one of 16 possible positions. This command is used in conjunction with the [Store Current Position \(#16\)](#) and [Return Stored Position \(#17\)](#) commands. This command does not send a response until the move has finished. All move commands are pre-emptive. If a new move command is issued before the previous move command is finished, the device will immediately move to the new position.

The target speed and acceleration during a move absolute instruction can be specified using [Set Target Speed \(Cmd 42\)](#) and [Set Acceleration \(Cmd 43\)](#) respectively.

This command may pre-empt, or be pre-empted by [Move to Stored Position \(Cmd 18\)](#), [Move Absolute \(Cmd 20\)](#), [Move Relative \(Cmd 21\)](#), [Move at Constant Speed \(Cmd 22\)](#), [Move Index \(Cmd 78\)](#) and [Stop \(Cmd 23\)](#).

Move Absolute - Cmd 20

| | |
|-------------------------|----------------------------|
| Instruction Name | Move Absolute |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 20 |

| | |
|----------------------------------|---|
| Command Type | Command |
| Command Data | Absolute Position |
| Reply Data | Final Position |
| Safe to retry? | Yes |
| Returns Current Position? | Yes |
| Persistence | n/a |
| Summary | Moves the device to the position specified in the Command Data in microsteps. |

The device begins to move immediately, and sends a response when the move has finished. The position must be between 0 and Maximum Position (specified by [Set Maximum Position \(cmd 44\)](#)), or an error code will be returned.

The target speed and acceleration during a move absolute instruction can be specified using [Set Target Speed \(Cmd 42\)](#) and [Set Acceleration \(Cmd 43\)](#) respectively.

All move commands are pre-emptive. If a new move command is issued before the previous move command is finished, the device will immediately move to the new position. This command may pre-empt, or be pre-empted by [Move to Stored Position \(Cmd 18\)](#), [Move Absolute \(Cmd 20\)](#), [Move Relative \(Cmd 21\)](#), [Move at Constant Speed \(Cmd 22\)](#) and [Stop \(Cmd 23\)](#).

Move Relative - Cmd 21

| | |
|----------------------------------|--|
| Instruction Name | Move Relative |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 21 |
| Command Type | Command |
| Command Data | Relative Position |
| Reply Data | Final Position |
| Safe to retry? | No |
| Returns Current Position? | Yes |
| Persistence | n/a |
| Summary | Moves the device by the positive or negative number of microsteps specified in the Command Data. |

The device moves to a position given by its current position plus the value specified in the command data. The relative move command data in microsteps can be positive or negative. The final position must be between 0 and Maximum Position (specified by [Set Maximum Position \(cmd 44\)](#)), or an error code will be returned. The device begins to move immediately, and sends a response when the move has finished.

The target speed and acceleration during a move absolute instruction can be specified using [Set Target Speed \(Cmd 42\)](#) and [Set Acceleration \(Cmd 43\)](#) respectively.

All move commands are pre-emptive. If a new move command is issued before the previous move command is finished, the device will immediately move to the new position. If a Move Relative command is issued while the device is currently moving due to a previous command, the device will immediately set a new target position equal to the current position (at the instant the command was received) plus the specified relative position.

This command may pre-empt, or be pre-empted by [Move to Stored Position \(Cmd 18\)](#), [Move Absolute \(Cmd 20\)](#), [Move Relative \(Cmd 21\)](#), [Move at Constant Speed \(Cmd 22\)](#) and [Stop \(Cmd 23\)](#).

Move At Constant Speed - Cmd 22

| | |
|----------------------------------|--|
| Instruction Name | Move At Constant Speed |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 22 |
| Command Type | Command |
| Command Data | Speed |
| Reply Data | Speed |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Moves the device at a constant speed based on the value specified in the Command Data. |

This instruction specifies a direction and a speed to move, rather than a target position. When this instruction is issued the device will accelerate (at a rate determined by [command #43 Set Acceleration](#)) to the speed specified by the instruction data. The device will continue moving at this speed until a limit is reached or a pre-empting instruction is issued. Negative speeds cause retraction while positive speeds cause extension. Unlike the other movement commands, this command sends a response immediately without waiting for the move to finish.

The device may be set to return its position continuously during the move using the [set mode command \(#40\)](#) bit 4. Position tracking is a reply-only command #8. If the device runs into zero position or maximum range, the device stops and the new position is returned via reply-only command #9.

This command may pre-empt, or be pre-empted by commands [18](#), [20](#), [21](#), [22](#) and [23](#).

For a spreadsheet that can be used to calculate speed setting values for any product see <https://www.zaber.com/documents/ZaberSpeedSetting.xls>. Alternatively you may use the formulas below.

Actual Speed

= Data * 9.375 * M mm/s or deg/s

= Data * 9.375 microsteps/s

= Data * 9.375 / R steps/s

= Data * 9.375 / (R x S) * 60 revolutions/min Motor rpm

= Data * 9.375 * L / (R x S) mm/s Linear devices only

where:

- Data is the value of the command data
- R (microsteps/step) is the microstep resolution (command 37)
- S (steps/revolution) is the number of steps per motor revolution
- M (mm or deg) is the microstep size
- L (mm or deg) is the distance of linear motion per motor revolution

Refer to product specifications for the distance corresponding to a single microstep or revolution.

For example, if a motor has 48 steps per revolution (S = 48), used with default resolution (R = 64), and Data is 2922, then the motor will move at a speed of approximately 535 revolutions per minute.

Valid data values are from $(-512 \times R - 1)$ to $(512 \times R - 1)$. Note that a value of zero will cause the device to decelerate to a stop and then send [Limit Active \(Cmd 9\)](#).

Stop - Cmd 23

| | |
|----------------------------------|--|
| Instruction Name | Stop |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 23 |
| Command Type | Command |
| Command Data | Ignored |
| Reply Data | Final Position |
| Safe to retry? | Yes |
| Returns Current Position? | Yes |
| Persistence | n/a |
| Summary | Stops the device from moving by preempting any move instruction. |

This instruction can be used to pre-empt any move instruction. The device will decelerate to a stop. The reply data is the absolute position after stopping.

The device will decelerate at a rate specified by [Set Acceleration \(Cmd 43\)](#).

This command may pre-empt, or be pre-empted by [Move to Stored Position \(Cmd 18\)](#), [Move Absolute \(Cmd 20\)](#), [Move Relative \(Cmd 21\)](#), [Move at Constant Speed \(Cmd 22\)](#) and [Stop \(Cmd 23\)](#).

Read Or Write Memory - Cmd 35

| | |
|-------------------------|----------------------------|
| Instruction Name | Read Or Write Memory |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 35 |

| | |
|----------------------------------|--|
| Command Type | Command |
| Command Data | Data |
| Reply Data | Data |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Reads or writes a byte of non-volatile memory. |

128 bytes of memory are available for user data. For example, the user may want to save some custom data such as a serial number, a name string, or data that uniquely identifies a particular device. Data written is not cleared by power down or reset. The most significant bit of byte 3 specifies whether the instruction is a read (0) or a write (1). The least significant 7 bits of byte 3 specify the address to read/write (0 to 127). Byte 4 specifies the value to be written. Bytes 5 and 6 are ignored.

These settings are stored in non-volatile memory and will persist after power-down or reset.

Restore Settings - Cmd 36

| | |
|----------------------------------|---|
| Instruction Name | Restore Settings |
| Applies to | All Zaber devices except controllers |
| Firmware Version | 5.00 and up |
| Command Number | 36 |
| Command Type | Command |
| Command Data | Peripheral ID |
| Reply Data | Peripheral ID |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Restores the device settings to the factory defaults. |

This command should be issued with a peripheral ID of 0 to return the device to factory default settings. This instruction is very useful for troubleshooting. If the device does not appear to function properly, it may be because some of the settings have been changed. This instruction will restore the settings to default values. For a table of default settings, see [Appendix A](#). All settings affected by this instruction are stored in non-volatile memory and will persist after power-down or reset.

Set Microstep Resolution - Cmd 37

| | |
|----------------------------------|--|
| Instruction Name | Set Microstep Resolution |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 37 |
| Command Type | Setting |
| Command Data | Microsteps |
| Reply Data | Microsteps |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Changes the number of microsteps per step. |

This command sets the microstep resolution of a device.

This setting is stored in non-volatile memory and will persist after power-down or reset. Use Restore Settings (Cmd 36) to restore all non-volatile settings to factory default.

The default on most devices is 64. Available microstep resolutions are:

1, 2, 4, 8, 16, 32, 64, 128

All position data sent to or received from T-Series products is in units of microsteps. Note that when you change the microstep resolution, other position related settings are scaled automatically from current values to adjust for the new microstep size. The table below gives an example showing how other

settings are affected when the microstep resolution is changed from 128 to 64:

| Setting | Before | After |
|-------------------------|--------|---------|
| Target Speed * | 2922 | 1461 |
| Maximum Travel Range * | 280000 | 140000 |
| Current Position | 10501 | 5250 ** |
| Maximum Relative Move * | 20000 | 10000 |
| Home Offset * | 1000 | 500 |
| Acceleration * | 100 | 50 |

* The settings for these commands are saved in non-volatile memory.

** Note that if a number is divided by two, it is rounded down to the nearest whole number. The only exception to this is if acceleration would become 0 (because 0 for acceleration indicates infinite acceleration). If acceleration would become 0, it will instead be set to 1 which is the lowest acceleration possible.

Set Running Current - Cmd 38

| | |
|----------------------------------|---|
| Instruction Name | Set Running Current |
| Applies to | T-series motorized devices (excluding T-LSQ , T-LST , T-MCA) |
| Firmware Version | 5.xx |
| Command Number | 38 |
| Command Type | Setting |
| Command Data | Value |
| Reply Data | Value |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Sets the desired current to be used when the device is moving. |

If your application does not require high torque, it is best to decrease the driving current to reduce power consumption, vibration, and motor heating. Trial and error should suggest an appropriate setting. If higher torque is required, it is generally safe to overdrive motors as long as they are not operated continuously. Motor temperature is typically the best indication of the degree to which overdriving can be employed. If the motor gets too hot to touch (>75°C), you should reduce the running current.

The current is related to the data by the formula:

$$\text{Current} = \text{CurrentCapacity} * 10 / \text{CommandData}$$

The range of accepted values is 0 (no current), 10 (max) - 127 (min). CurrentCapacity is the hardware's maximum capability of output current.

To prevent damage, some devices limit the maximum output current to a lower value. In that case the valid range is 0, Limit - 127. Current limits are listed under the device specifications.

Some devices limit the voltage rather than the current. In this case the same formula can be used by replacing Current and CurrentCapacity with Voltage and PowerSupplyVoltage.

For example, Suppose you connect a stepper motor rated for 420mA per phase to a T-CD2500. Reversing the equation above and using 420mA as Current gives:

$$\begin{aligned} \text{CommandData} &= 10 * \text{CurrentCapacity} / \text{Current} \\ &= 10 * 2500\text{mA} / 420\text{mA} \\ &= 59.5 \text{ (round to 60)} \end{aligned}$$

Therefore CommandData = 60.

Set Hold Current - Cmd 39

| | |
|-------------------------|---|
| Instruction Name | Set Hold Current |
| Applies to | T-series motorized devices (excluding T-LSQ , T-LST , T-MCA) |
| .. | - |

| | |
|----------------------------------|--|
| Firmware Version | 5.xx |
| Command Number | 39 |
| Command Type | Setting |
| Command Data | Value |
| Reply Data | Value |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Sets the desired current to be used when the device is holding its position. |

It is typical to run stepper motors at their rated current only during moves (for highest torque) and reduce the current when idle just to hold the position.

Typically the hold current can be set to around 25 - 50% of the running current. In some applications, the friction of the drive system alone is sufficient to hold the microstep position of the motor, and the hold current can be turned off completely. The hold current can be turned off by issuing the "Set Hold Current" instruction with data of 0.

When the device is moving, it applies running current to the motor. When the device stops moving, running current is applied for an additional 0.1 second before hold current is applied.

The current is related to the data by the formula:

$$\text{Current} = \text{CurrentCapacity} * 10 / \text{CommandData}$$

The range of accepted values is 0 (no current), 10 (max) - 127 (min). CurrentCapacity is the hardware's maximum capability of output current.

To prevent damage, some devices limit the maximum output current to a lower value. In that case the valid range is 0, Limit - 127. Current limits are listed under the device specifications.

Some devices limit the voltage rather than the current. In this case the same formula can be used by replacing Current and CurrentCapacity with Voltage and PowerSupplyVoltage.

For example, Suppose you connect a stepper motor rated for 420mA per phase to a T-CD2500. Reversing the equation above and using 420mA as Current gives:

$$\begin{aligned} \text{CommandData} &= 10 * \text{CurrentCapacity} / \text{Current} \\ &= 10 * 2500\text{mA} / 420\text{mA} \\ &= 59.5 \text{ (round to 60)} \end{aligned}$$

Therefore CommandData = 60.

Set Device Mode - Cmd 40

| | |
|----------------------------------|-------------------------------------|
| Instruction Name | Set Device Mode |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx since 5.04 |
| Command Number | 40 |
| Command Type | Setting |
| Command Data | Mode |
| Reply Data | Mode |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Sets the Mode for the given device. |

This command allows setting several options. Each option is controlled by a single bit within the command data. Most software you will encounter, including most of our demo software, represents all 4 data bytes as a single decimal value rather than specifying each bit individually. To determine what decimal value to use requires a basic understanding of how the data is represented in binary. The command data may be considered as a single 32-bit binary value. The least significant bit is bit_0, the next is bit_1, the next is bit_2, and so on up to the most significant bit_31. Each bit may have a value of either 1 or 0.

The corresponding decimal representation of this 32-bit data is given by:

$$\text{Decimal value} = (\text{bit}_0 * 1) + (\text{bit}_1 * 2) + \dots + (\text{bit}_n * 2^n) + \dots + (\text{bit}_{31} * 2^{31})$$

Each bit controls a single mode option as described in the table below. To determine the data value to use with the Set Device Mode command, simply determine the desired value of each bit (1 or 0), and calculate the decimal value using the above formula. Note that not all 32 bits are currently used. Any unused or reserved bits should be left as 0.

For example, suppose you want all mode bits to be 0 except for bit_3 (disable potentiometer), bit_14 (disable power LED), and bit_15 (disable serial LED). The Set Device Mode instruction should be sent with data calculated as follows:

$$\begin{aligned} \text{Command Data} &= 2^3 + 2^{14} + 2^{15} \\ &= 8 + 16384 + 32768 \\ &= 49160 \end{aligned}$$

Note that each instance of the Set Device Mode command overwrites ALL previous mode bits. Repeated commands do not have a cumulative effect. For example, suppose you send a Set Device Mode command with data of 8 to disable the potentiometer. If you then send another Set Device Mode command with data of 16384 to disable the power LED, you will re-enable the potentiometer since bit_3 in the 2nd instruction is 0.

Most devices have a default mode setting of 0 (all bits are 0), however, there are some exceptions. See Appendix A of the user manual for a table of default settings.

| Bit_n | 2^n | Description |
|--------|-------|--|
| bit_0 | 1 | Disable Auto-reply A value of 1 disables ALL replies except those to "echo", "read", "renumber", and "return" commands. The default value is 0 on all devices. |
| bit_1 | 2 | Enable Anti-backlash Routine A value of 1 enables anti-backlash. On negative moves (retracting), the device will overshoot the desired position by 640 microsteps (assuming 64 microsteps/step), reverse direction and approach the requested position from below. On positive moves (extending), the device behaves normally. Care must be taken not to crash the moving payload into a fixed object due to the 640 microsteps overshoot on negative moves. The default value is 0 on all devices. See note on anti-backlash and anti-sticktion below. * |
| bit_2 | 4 | Enable Anti-sticktion Routine A value of 1 enables the anti-sticktion routine. On moves less than 640 microsteps (assuming 64 microsteps/step), the device will first retract to a position 640 microsteps less than the requested position and approach the requested position from below. Care must be taken not to crash the moving payload into a fixed object due to the 640 microsteps negative move. The default value is 0 on all devices. See section on anti-backlash and anti-sticktion below this table. * |
| bit_3 | 8 | Disable Potentiometer A value of 1 disables the potentiometer preventing manual adjustment of the device. The default value is 0 on all devices. |
| bit_4 | 16 | Enable Move Tracking A value of 1 enables the Move Tracking response during move commands. The device will return its position periodically (every 0.25 sec) when a move command is executed. The Disable Auto-Reply option above takes precedence over this option. The default value is 0 on all devices. Before firmware version 5.14, only Move at Constant Speed commands could generate tracking responses, now all move commands can. |
| bit_5 | 32 | Disable Manual Move Tracking A value of 1 disables the Manual Move Tracking response during manual moves. The Disable Auto-Reply option above takes precedence over this option. The default value is 0 on all devices. |
| bit_6 | 64 | Enable Message IDs A value of 1 enables Message IDs. In this mode of communication, only bytes 3 through 5 are used for data. Byte 6 is used as an ID byte that the user can set to any value they wish. It will be returned unchanged in the reply. Message IDs allow the users application to monitor communication packets individually to implement error detection and recovery. The default value is 0 on all devices. Prior to firmware version 5.06, this feature was called "Virtual Channels Mode" and did not behave reliably. We do not recommend enabling this mode of communications unless you have firmware version 5.06 or later. |
| bit_7 | 128 | Home Status This bit is set to 0 automatically on power-up or reset. It is set automatically when the device is homed or when the position is set using command #45. It can be used to detect if a device has a valid position reference. It can also be set or cleared by the user. |
| bit_8 | 256 | Disable Auto-Home A value of 1 disables auto-home checking. Checking for trigger of home sensor is only done when home command is issued. This allows rotational devices to move multiple revolutions without re-triggering the home sensor. |
| bit_9 | 512 | Reverse Potentiometer A value of 1 reverses the direction of the travel when the potentiometer is used to control the device. This mode bit was introduced in firmware version 5.06. Prior to that it was not used. |
| bit_10 | 1,024 | Reserved |
| bit_11 | 2,048 | Microstepping Mode |

A value of 1 enables circular phase microstepping. A value of 0 enables square phase microstepping mode. The differences are:

Circular Phase:

- constant torque
- smoothest operation
- better microstep accuracy
- only 70% torque (and lower power consumption)

Square Phase:

- non constant torque
- less smooth operation
- poorer microstep accuracy
- 100% torque achieved (and higher power consumption)

bit_12 4,096 **Reserved**

bit_13 8,192 **Reserved**

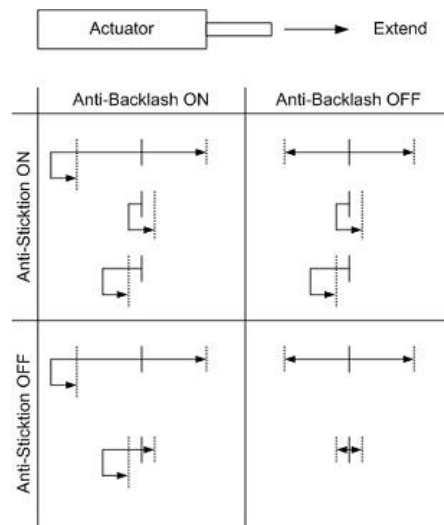
bit_14 16,384 **Disable Power LED**

A value of 1 turns off the green power LED. It will still blink briefly, immediately after powerup.

bit_15 32,768 **Disable Serial LED**

A value of 1 turns off the yellow serial LED.

*Anti-backlash and Anti-sticktion routines are designed to compensate for backlash and sticktion. The solution to backlash is to always approach a position from the same direction. The solution to sticktion is to move the device far enough away from the final position to break free of sticktion before attempting the final move. The operation of the two features are dependent on each other, and the interaction of enabling one or both of the features is described in the diagram to the right.



For each setting scenario, the starting position is denoted by the solid vertical line and the final position is denoted by the dotted vertical line. There are four possible moves for each scenario: long move positive, long move negative, short move positive and short move negative. The arrows show the path that would be traversed for each scenario.

Set Home Speed - Cmd 41

| | |
|----------------------------------|----------------------------|
| Instruction Name | Set Home Speed |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx since 5.20 |
| Command Number | 41 |
| Command Type | Setting |
| Command Data | Speed |
| Reply Data | Speed |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |

Summary Sets the speed at which the device moves when using the "Home" command.

When a home instruction is issued, the device will accelerate at a rate determined by the acceleration setting up to the speed determined by this command. The home speed can be set independently of target speed (command 42) so that for stages that move very fast, issuing the home command would use a slower home speed and prevent the stage from crashing into the home position.

For a spreadsheet that can be used to calculate speed setting values for any product see <https://www.zaber.com/documents/ZaberSpeedSetting.xls>. Alternatively you may use the formulas below.

Actual Speed

= Data * 9.375 * M mm/s or deg/s

= Data * 9.375 microsteps/s

= Data * 9.375 / R steps/s

= Data * 9.375 / (R x S) * 60 revolutions/min Motor rpm

= Data * 9.375 * L / (R x S) mm/s Linear devices only

where:

- Data is the value of the command data
- R (microsteps/step) is the microstep resolution (command 37)
- S (steps/revolution) is the number of steps per motor revolution
- M (mm or deg) is the microstep size
- L (mm or deg) is the distance of linear motion per motor revolution

Refer to product specifications for the distance corresponding to a single microstep or revolution.

For example, if a motor has 48 steps per revolution (S = 48), used with default resolution (R = 64), and Data is 2922, then the motor will move at a speed of approximately 535 revolutions per minute.

Valid data values are from 1 to (512×R-1).

Set Target Speed - Cmd 42

| | |
|----------------------------------|--|
| Instruction Name | Set Target Speed |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 42 |
| Command Type | Setting |
| Command Data | Speed |
| Reply Data | Speed |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Sets the speed at which the device moves when using the "Move Absolute" or "Move Relative" commands. |

When a move absolute or move relative instruction is issued, the device will accelerate at a rate determined by the acceleration setting up to the speed determined by this command.

The target velocity may be changed on-the-fly even when the device is in the middle of a move. The device will automatically adjust the velocity, but still target the final position specified in the original move.

For a spreadsheet that can be used to calculate speed setting values for any product see <https://www.zaber.com/documents/ZaberSpeedSetting.xls>. Alternatively you may use the formulas below.

Actual Speed

= Data * 9.375 * M mm/s or deg/s

= Data * 9.375 microsteps/s

= Data * 9.375 / R steps/s

= Data * 9.375 / (R x S) * 60 revolutions/min Motor rpm

= Data * 9.375 * L / (R x S) mm/s Linear devices only

where:

- Data is the value of the command data
- R (microsteps/step) is the microstep resolution (command 37)
- S (steps/revolution) is the number of steps per motor revolution
- M (mm or deg) is the microstep size
- L (mm or deg) is the distance of linear motion per motor revolution

Refer to product specifications for the distance corresponding to a single microstep or revolution.

For example, if a motor has 48 steps per revolution (S = 48), used with default resolution (R = 64), and Data is 2922, then the motor will move at a speed of approximately 535 revolutions per minute.

Valid data values are from 0 to (512×R-1). In Firmware 5.21 and 5.22, a value of 0 is not allowed. In all other versions, target speed of 0 will cause Move Absolute/Relative and Move to Stored Position commands to return an error.

Set Acceleration - Cmd 43

| | |
|----------------------------------|--|
| Instruction Name | Set Acceleration |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 43 |
| Command Type | Setting |
| Command Data | Acceleration |
| Reply Data | Acceleration |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Sets the acceleration used by the movement commands. |

When a movement command is issued, the device will accelerate at a rate determined by this command "Set Acceleration" up to a maximum speed determined by the target velocity. The acceleration may be changed on-the-fly even when the device is in the middle of a move. To determine the acceleration that will result from a given data value, the following formulas may be used:

Actual Acceleration

$$= 11250 * \text{Data} * M \text{ mm/s}^2 \text{ or deg/s}^2$$

$$= 11250 * \text{Data} \text{ microsteps/s}^2$$

$$= 11250 * \text{Data} / R \text{ steps/s}^2$$

Where:

- Data is the value specified in the Command Data
- M (mm or deg) is the microstep size
- R is the microstep resolution set in command #37 (microsteps/step)

The maximum value allowable is (512×R-1). This is the same as the maximum allowable data for velocity, which means that the device will reach maximum velocity immediately. If acceleration is set to 0, it is as if acceleration is set to (512×R-1). Effectively acceleration is turned off and the device will start moving at the target speed immediately.

Set Maximum Position - Cmd 44

| | |
|----------------------------------|----------------------------|
| Instruction Name | Set Maximum Position |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 44 |
| Command Type | Setting |
| Command Data | Range |
| Reply Data | Range |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |

Summary Sets the maximum position the device is allowed to travel to.

Use this command to limit the range of travel to a value other than the default. Exercise caution when using this command, since it is possible to set the range to a value greater than the physical limits of the device.

A device within range of travel is not allowed to move above its Maximum Position. Valid values can be any number from 0 to 16777215.

The behaviour of this command depends on the firmware version:

5.01 - 5.20

Device movement behaviour when out of range is not well-defined.

5.21 - 5.22

The new Maximum Position cannot be less than the current position.

5.23 and up

If the device Current Position is out of range and above Maximum Position, the device is not allowed to move in the positive direction.

This setting is stored in non-volatile memory and will persist after power-down or reset.

NOTE: This command was previously named Set Maximum Range.

Set Current Position - Cmd 45

| | |
|----------------------------------|--|
| Instruction Name | Set Current Position |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 45 |
| Command Type | Setting |
| Command Data | New Position |
| Reply Data | New Position |
| Safe to retry? | Yes |
| Returns Current Position? | Yes |
| Persistence | Volatile |
| Summary | Sets the device internal position counter. |

This command override the internal position counter with a new position value specified by the user.

The position data is volatile and will not persist after power-down or reset.

The phase of the stepper motor is controlled by the least significant byte of the position, thus the device may move by +/- 2 full steps unless the new position corresponds to the true current position of the device. This command is useful if you want to turn off the system without losing position. Simply save the position in the controlling computer and turn off the **hold current (Command 39)** before powering down. After powering up, set the position back to the saved value and turn on the hold current. In this way you can continue without having to home the device. You have to turn off the hold current because when the power first comes on the position will default to the maximum range, and that may be out of phase with the motor's current position. If the hold current is on, it will force the motor into phase with the default position before you've had a chance to restore the current position.

In Firmware 5.21 and 5.22, the new Current Position must be equal or less than Maximum Position. See **Set Maximum Position (Cmd 44)** for more details on range settings and behaviour.

Set Maximum Relative Move - Cmd 46

| | |
|----------------------------------|----------------------------|
| Instruction Name | Set Maximum Relative Move |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 46 |
| Command Type | Setting |
| Command Data | Range |
| Reply Data | Range |
| Safe to retry? | Yes |
| Returns Current Position? | No |

| | |
|----------------------------------|---|
| Returns Current Position? | No |
| Persistence | Non-volatile |
| Summary | Sets a limit on the number of microsteps the device can make for a Relative Move command. |

Use this command to limit the maximum range of travel for a relative move command. For example, if maximum relative move is set to 1000, and the user requests a relative move (#21) of 800, then the device will move 800 microsteps. However, if the user requests a relative move of 1200, then the device will reply with an error code. Most applications can leave this unchanged from the default.

This setting is stored in non-volatile memory and will persist after power-down or reset.

Set Home Offset - Cmd 47

| | |
|----------------------------------|--|
| Instruction Name | Set Home Offset |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 47 |
| Command Type | Setting |
| Command Data | Offset |
| Reply Data | Offset |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Sets the the new "Home" position which can then be used when the Home command is issued. |

When the home command is issued, the device will retract until the home sensor is triggered, then move forward until the home sensor is no longer triggered, then move forward by the Home Offset value (in microsteps) and resets the internal position (to 0 for most devices).

Note that the home offset command also changes the range settings of the device. For example, if the initial Home Offset is 0 and the Maximum Position is 500,000, and the user changes the Home Offset to 70,000, then the Maximum Position is automatically adjusted to be 430,000. However, changing the Maximum Position does not affect the home offset.

When a new Home Offset is specified, Maximum Position is adjusted to provide the same maximum location. However, the device will not be able to travel below its new home position unless it is homing.

This setting is stored in non-volatile memory and will persist after power-down or reset.

Set Alias Number - Cmd 48

| | |
|----------------------------------|---|
| Instruction Name | Set Alias Number |
| Applies to | All Zaber devices |
| Firmware Version | 5.00 and up |
| Command Number | 48 |
| Command Type | Setting |
| Command Data | Alias Number |
| Reply Data | Alias Number |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Sets an alternate device number for a device. |

This setting specifies an alternate device number for a device (in addition to its actual device number). By setting several devices to the same alias number, you can control a group of devices with a single instruction. When you send an instruction to an alias number, all devices with that alias number will execute the instruction and reply using their actual device numbers. To remove an alias, simply set the device's alias number to zero. Valid alias numbers are 0 to 99 for version 6.05, and 0 to 254 otherwise. To avoid confusion, it is best to choose an alias greater than the number of devices connected.

This setting is stored in non-volatile memory and will persist after power-down or reset.

Set Lock State - Cmd 49

| | |
|-------------------------|------------------|
| Instruction Name | Set Lock State |
| Applies to | T-Series devices |

| | |
|----------------------------------|---|
| Firmware Version | 5.xx since 5.07 |
| Command Number | 49 |
| Command Type | Setting |
| Command Data | Lock State |
| Reply Data | Lock State |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | Non-Volatile |
| Summary | Locks or unlocks all non-volatile settings. |

Sometimes it is desirable to lock all non-volatile settings to prevent them from being changed inadvertently. After changing all settings as desired, settings can be locked by setting the Lock State to 1. Subsequent attempts to change any non-volatile setting (e.g., Set Target Speed, command 42) will result in an **error response** with an error code of 3600 (settings locked). Note that the Set Lock State command does not apply to commands and settings that are specific to the **T-JOY3 joystick**. **Load Event Instruction** and **Set Axis Device Number** for example, are unaffected by the Lock State.

How the **Restore Settings** instruction behaves when the settings are locked depends on the firmware version. In version 5.07 issuing a Restore Settings instruction while the settings are locked will result in an **error response** with an error code of 3600 (settings locked). This behavior was found to confuse many customers so in version 5.08 and up, the behavior was changed such that regardless of the current lock state, issuing a Restore Settings instruction will always return setting values to factory default values and leave settings in an unlocked state.

Settings can also be unlocked by setting the Lock State to 0.

Return Device ID - Cmd 50

| | |
|----------------------------------|---|
| Instruction Name | Return Device ID |
| Applies to | All Zaber devices |
| Firmware Version | 5.00 and up |
| Command Number | 50 |
| Command Type | Read-Only Setting |
| Command Data | Ignored |
| Reply Data | Device ID |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Returns the ID number for the type of device connected. |

See the [Zaber support web site](#) for a table of device IDs for all Zaber products.

Return Firmware Version - Cmd 51

| | |
|----------------------------------|---|
| Instruction Name | Return Firmware Version |
| Applies to | All Zaber devices |
| Firmware Version | 5.00 and up |
| Command Number | 51 |
| Command Type | Read-Only Setting |
| Command Data | Ignored |
| Reply Data | Version |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Returns the firmware version installed on the device. |

A decimal is assumed before the last two digits. For example, 502 indicates firmware version 5.02.

Return Power Supply Voltage - Cmd 52

| | |
|-------------------------|-----------------------------|
| Instruction Name | Return Power Supply Voltage |
| Applies to | All Zaber devices |

| | |
|----------------------------------|---|
| Firmware Version | 5.00 and up |
| Command Number | 52 |
| Command Type | Read-Only Setting |
| Command Data | Ignored |
| Reply Data | Voltage |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Returns the voltage level of the device's power supply. |

A decimal is assumed before the last digit. For example, a value of 127 indicates 12.7 V. Note that the internal voltage measurement is not very accurate. Don't be alarmed if the indicated voltage is slightly different from your measurements.

Return Setting - Cmd 53

| | |
|----------------------------------|---|
| Instruction Name | Return Setting |
| Applies to | All Zaber devices |
| Firmware Version | 5.00 and up |
| Command Number | 53 |
| Command Type | Command |
| Command Data | Setting Number |
| Reply Data | Setting Value |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Returns the current value of the setting specified in the Command Data. |

Valid command data values are the command numbers of any "Set..." instruction. The device will reply using the command number of the specified setting (as if a command to change the setting had just been issued) but the setting will not be changed.

For example, command #48 is the "Set Alias" instruction. Therefore if you wish to return the current value of the alias number, simply send the Return Setting instruction with data of 48. The device will reply with command #48 and data equal to the setting value.

Since firmware version 5.21, this command also accepts the command numbers of any "Return..." instruction, such as command #50 "Return Device ID".

Return Status - Cmd 54

| | |
|----------------------------------|---|
| Instruction Name | Return Status |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 54 |
| Command Type | Read-Only Setting |
| Command Data | Ignored |
| Reply Data | Status |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Returns the current status of the device. |

Possible status codes are as follows:

- 0 - idle, not currently executing any instructions
- 1 - executing a home instruction
- 10 - executing a manual move (i.e. the manual control knob is turned)
- 18 - executing a move to stored position instruction (FW 5.04 and up only)
- 20 - executing a move absolute instruction
- 21 - executing a move relative instruction
- 22 - executing a move at constant speed instruction

- 23 - executing a stop instruction (i.e. decelerating)

Echo Data - Cmd 55

| | |
|----------------------------------|--|
| Instruction Name | Echo Data |
| Applies to | All Zaber devices |
| Firmware Version | 5.04 and up |
| Command Number | 55 |
| Command Type | Command |
| Command Data | Data |
| Reply Data | Data |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Echoes back the same Command Data that was sent. |

This command is useful for testing communication, similar to a network "ping".

Return Current Position - Cmd 60

| | |
|----------------------------------|--|
| Instruction Name | Return Current Position |
| Applies to | All motorized devices |
| Firmware Version | 5.00 and up |
| Command Number | 60 |
| Command Type | Read-Only Setting |
| Command Data | Ignored |
| Reply Data | Position |
| Safe to retry? | Yes |
| Returns Current Position? | Yes |
| Persistence | n/a |
| Summary | Returns the current absolute position of the device in microsteps. |

This is equivalent to issuing a [Return Setting \(#53\)](#) command with a command data value of 45 (Set Current Position).

Return Serial Number - Cmd 63

| | |
|----------------------------------|--|
| Instruction Name | Return Serial Number |
| Applies to | All devices |
| Firmware Version | 5.30 to 5.35, 6.07 and up |
| Command Number | 63 |
| Command Type | Read-Only Setting |
| Command Data | Ignored |
| Reply Data | Serial Number |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Returns the serial number of the device. |

In general, a Zaber device will reply to an instruction using the same command number as the instruction itself. However, there are occasions (such as when the user turns a manual control knob) when the device may transmit data without first receiving a request from the controlling computer. This type of reply may be considered to be a triggered reply as opposed to a requested reply. In this case the device uses a "reply-only" command number to distinguish the reply from those requested by the controlling computer. The meanings of these replies and their corresponding data are given below.

Move Tracking - Cmd 8

| | |
|-------------------------|----------------------------|
| Instruction Name | Move Tracking |
| Applies to | T-Series motorized devices |

| | |
|----------------------------------|--|
| Firmware Version | 5.xx |
| Command Number | 8 |
| Command Type | Reply |
| Command Data | n/a |
| Reply Data | Position |
| Safe to retry? | Yes |
| Returns Current Position? | Yes |
| Persistence | n/a |
| Summary | Indicates to the user that the device has been set to a position tracking mode and given a move instruction. |

Move Tracking has been enabled (see [Set Device Mode \(Cmd 40\)](#)) and device has been given a move instruction. In this mode, the device sends this reply every 0.25 seconds updating the current absolute position (in microsteps) during any move.

Limit Active - Cmd 9

| | |
|----------------------------------|--|
| Instruction Name | Limit Active |
| Applies to | All motorized devices |
| Firmware Version | 5.00 and up |
| Command Number | 9 |
| Command Type | Reply |
| Command Data | n/a |
| Reply Data | Position |
| Safe to retry? | Yes |
| Returns Current Position? | Yes |
| Persistence | n/a |
| Summary | Indicates to the user that the device has reached one of the limits of travel. |

This response from a device indicates that a "move at constant speed" command has finished. Generally this is because the device reached one of the limits of travel (either the minimum position or maximum position), but it also occurs if the device is ordered to move at constant speed zero.

Manual Move Tracking - Cmd 10

| | |
|----------------------------------|--|
| Instruction Name | Manual Move Tracking |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 10 |
| Command Type | Reply |
| Command Data | n/a |
| Reply Data | Position |
| Safe to retry? | Yes |
| Returns Current Position? | Yes |
| Persistence | n/a |
| Summary | A reply that is sent when the manual control knob is turned. |

Manual Move Tracking has been enabled (see [Set Device Mode \(Cmd 40\)](#)) and the device has been moved manually (the knob is turned). In this mode, the device sends this reply every 0.25 seconds updating the current absolute position (in microsteps) during any move.

Error - Cmd 255

| | |
|-------------------------|----------------------------|
| Instruction Name | Error |
| Applies to | T-Series motorized devices |
| Firmware Version | 5.xx |
| Command Number | 255 |
| Command Type | Reply |
| Command Data | n/a |

| | |
|----------------------------------|---|
| Reply Data | Error Code |
| Safe to retry? | Yes |
| Returns Current Position? | No |
| Persistence | n/a |
| Summary | Indicates to the user that an error has occurred. |

This reply indicates that an error has occurred. The error code returned in the data indicates the type of error. The device may send an error code as a reply to an invalid instruction, or it may autonomously send an error code as a triggered reply (i.e. not in response to an instruction). The error code is typically the command number of the instruction that caused the error, but not always.

Error Codes

| Code | Name | Description |
|------|-------------------------------|---|
| 1 | Cannot Home | Home - Device has traveled a long distance without triggering the home sensor. Device may be stalling or slipping. |
| 2 | Device Number Invalid | Renumbering data out of range. |
| 14 | Voltage Low | Power supply voltage too low. |
| 15 | Voltage High | Power supply voltage too high. |
| 18 | Stored Position Invalid | The position stored in the requested register is no longer valid. This is probably because the maximum range was reduced. |
| 20 | Absolute Position Invalid | Move Absolute - Target position out of range. |
| 21 | Relative Position Invalid | Move Relative - Target position out of range. |
| 22 | Velocity Invalid | Constant velocity move. Velocity out of range. |
| 36 | Peripheral Id Invalid | Restore Settings - peripheral id is invalid. Please use one of the peripheral ids listed in the user manual, or 0 for default. |
| 37 | Resolution Invalid | Invalid microstep resolution. Resolution may only be 1, 2, 4, 8, 16, 32, 64, 128. |
| 38 | Run Current Invalid | Run current out of range. See command 38 for allowable values. |
| 39 | Hold Current Invalid | Hold current out of range. See command 39 for allowable values. |
| 40 | Mode Invalid | Set Device Mode - one or more of the mode bits is invalid. |
| 41 | Home Speed Invalid | Home speed out of range. The range of home speed is determined by the resolution. |
| 42 | Speed Invalid | Target speed out of range. The range of target speed is determined by the resolution. |
| 43 | Acceleration Invalid | Target acceleration out of range. The range of target acceleration is determined by the resolution. |
| 44 | Maximum Range Invalid | The maximum range may only be set between 1 and the resolution limit of the stepper controller, which is 16,777,215. |
| 45 | Current Position Invalid | Current position out of range. Current position must be between 0 and the maximum range. |
| 46 | Maximum Relative Move Invalid | Max relative move out of range. Must be between 0 and 16,777,215. |
| 47 | Offset Invalid | Home offset out of range. Home offset must be between 0 and maximum range. |
| 48 | Alias Invalid | Alias out of range. |
| 49 | Lock State Invalid | Lock state must be 1 (locked) or 0 (unlocked). |
| 53 | Setting Invalid | Return Setting - data entered is not a valid setting command number. Valid setting command numbers are the command numbers of any "Set ..." instructions. |
| 64 | Command Invalid | Command number not valid in this firmware version. |
| 255 | Busy | Another command is executing and cannot be pre-empted. Either stop the previous command or wait until it finishes before trying again. |
| 1600 | Save Position Invalid | Save Current Position register out of range (must be 0-15). |
| 1601 | Save Position Not Homed | Save Current Position is not allowed unless the device has been homed. |
| 1700 | Return Position Invalid | Return Stored Position register out of range (must be 0-15). |
| 1800 | Move Position Invalid | Move to Stored Position register out of range (must be 0-15). |
| 1801 | Move Position Not Homed | Move to Stored Position is not allowed unless the device has been homed. |
| 2146 | Relative Position Limited | Move Relative (command 20) exceeded maximum relative move range. Either move a shorter distance, or change the maximum relative move (command 46). |
| 3600 | Settings Locked | Must clear Lock State (command 49) first. See the Set Lock State command for details. |
| 4008 | Disable Auto Home Invalid | Set Device Mode - this is a linear actuator; Disable Auto Home is used for rotary actuators only. |
| 4010 | Bit 10 Invalid | Set Device Mode - bit 10 is reserved and must be 0. |

| | | |
|------|---------------------|---|
| 4012 | Home Switch Invalid | Set Device Mode - this device has integrated home sensor with preset polarity; mode bit 12 cannot be changed by the user. |
| 4013 | Bit 13 Invalid | Set Device Mode - bit 13 is reserved and must be 0. |

Turning the potentiometer knob will make the device move. It is not necessary to have a computer connected to use the device in manual mode. However, without a computer connected you have no means to initialize the device with a starting position. Therefore you must retract it completely after each power up in order to home the device. You will not be able to extend it fully until you have first retracted it completely to set the home position. Clockwise rotation of the knob produces positive motion (extension) and counter clockwise rotation produces negative motion (retraction).

The speed of retraction or extension will be directly related to the amount to which the knob is turned from its center detent position (turning the knob to its center position will stop the device from moving). During manual moves, the device constantly returns its position so a computer can track the position even when you are controlling the device manually. Manual control can be disabled with a mode setting.

The speed of the potentiometer-controlled manual moves is also determined by the Set Target Velocity command (#42). When the knob is fully turned to either limit, the device will move at the maximum velocity set by command #42. Any intermediate position of the knob will move the device at a velocity proportional to how far the knob has been turned. If the velocity is set to be very small, it may appear that turning the knob produces no movement. The way to verify that the actuator is moving is to connect it to a computer and monitor the replies back to the computer.

During operation if the actuator is extended or retracted against a force greater than its thrust capability the device will stall and there will be "missed steps". This can result in an apparent malfunction in that the device believes its position to be other than it actually is and will not extend or retract the actuator past a given position. Without connecting a computer to home the device or set its position, the only solution is to retract the actuator until it activates the internal home switch, which will automatically zero the device at the home position. A problem arises if the device incorrectly believes its position to be zero since it will not retract to the home position. In this case you must disconnect and reconnect the power before manually homing the device.

The green LED is on whenever there is power to the device. A constant blinking (2Hz) of the green LED indicates that the power supply is out of range. The green LED may be disabled by a mode bit (see command #40)

The amber or red LED flashes when there is traffic packet on the RS232 line. It also stays on while the device is moving. When the potentiometer is turned, the amber or red LED will blink at a rate that is proportional to how far the potentiometer is turned. The farther the knob is turned away from center detent, the faster the LED will blink. If the device reaches either the home or the away limit while under manual control, the LED will blink slowly to indicate that the device cannot move any farther.

| Symptom | Check |
|--|---|
| After the device finishes a move command, it starts moving again on its own. | The potentiometer knob is probably not centered. Make sure the knob is set to the middle position. You can feel a slight detent in the middle of its rotation. |
| Two or more devices both respond to commands sent to device 1. | Most devices are shipped with their device number set as 1. If you connect the devices through Zaber Console, you will be prompted to renumber them. If you aren't able to install and open Zaber Console, send the Renumber Instruction (command 2) in the software you are using to set all of the device numbers to different values. |
| Device starts turning as soon as the power is on or amber LED blinks all the time | The potentiometer is probably not centered. Turn the knob slowly until you feel the center detent. |
| Nothing happens when I turn the potentiometer knob either way. | Manual control may have been disabled. Issue the Restore Settings Instruction (command 36) or enable the potentiometer using the Set Device Mode Instruction (command 40). |
| Nothing happens when I send a move instruction. | The device needs to be "homed" first. You must issue the Home Instruction (command 1) after power up to home the device. |
| When I try to move the device it just makes a noise and vibrates. | There may be too much load that the device is trying to push. The actuator stalls in this situation. Try removing the load and see if the problem goes away. You can achieve higher thrust or torque by lowering the speed of the device using the Set Target Speed Instruction (command 42). |
| Stall condition: The device makes noise but does not move. | Try removing all external loads. If the device now extends and retracts normally, the problem is excessive load. Try to reduce the load or change step time and acceleration parameters to ensure the load is less than the maximum thrust. If a linear motion device is stalled in its fully extended position and remains stalled without any external load applied it means the lead screw has been over extended and is stuck. You can usually get the lead screw unstuck by pushing on it after issuing the home command. If a device is stalled (with no external load) in a position that is not fully extended then it requires servicing. |
| There is no communication between the computer and my Zaber device, the amber light does not come on or flash. | There are several things you should check: <ul style="list-style-type: none"> ▪ Make sure you have the correct serial port selected. Try selecting other serial ports in the software. To ensure that your serial port is working properly, you can connect the send and receive pins of the serial adaptor without connecting any devices. Use a wire to connect pins 2 and 6. Your software should echo a reply every time you send an instruction. You can view the pinout diagram here. ▪ Check the baud rate, hand shaking, parity, stop bit, etc. when configuring your serial communications software. The required settings are listed in the Control Through The RS-232 Serial Port section above. Also make sure that your serial port is not configured with a termination character (it often defaults to linefeed). ▪ Make sure there are no bent pins in the ends of all the data cables ▪ Make sure the power supply is working. Check the voltage over the DC plug to see if it measures close to the rated voltage for the supply. ▪ Make sure the power plug is plugged in all the way. If your device has LEDs, the green LED should light. |

| | |
|---|--|
| | <ul style="list-style-type: none"> ▪ If your device has a manual control knob, make sure it is centered (you should feel a detent in the center position). ▪ If your computer is a laptop running on batteries, try plugging in the power. Some laptops disable the serial ports when running on batteries. ▪ Make sure you do not have a null modem adaptor or cable in the line. ▪ The serial to mini-din adaptor comes in many varieties and many have different pin connections. Check the adaptor for continuity on the proper pins by consulting the adaptor pin-out diagram above. ▪ If you encounter the problem when trying to control the device with your own software, try using one of the demo programs from our website to verify that the hardware is functioning properly. |
| My device is behaving strangely. It responds to some commands as expected but not to others. | <ul style="list-style-type: none"> ▪ Send a Restore Settings Instruction (command 36). A setting might have been inadvertently changed. If you have a T-MCA or T-CD series stepper motor controller, note that a data value should be entered with the Restore Default Settings Instruction corresponding to the Peripheral Id of the device you are controlling. ▪ Your computer might be set to Unicode. This is common for languages that use non-Latin based characters. Go to Control Panel/Regional and Language Options/Advanced. Select a language for non-unicode programs. This should be English or another Latin based character language. |
| The device is moving very slowly. It used to behave differently. | The speed settings may have been changed inadvertently. Send a Restore Settings Instruction (command 36). |
| The device is not communicating or responding to computer control. The yellow LED may be blinking. | If the actuator has a manual control knob, make sure the knob is centered. Turn it back and forth until you feel a click or detent. Leave the knob at the center detent position. Then turn device off and on, and try again. |
| Green LED does not come on | Check the A/C wall plug, the voltage adaptor and its connection to the device. If the power is coming over the data cable, check the mini din connector for bent or broken pins. The amber light should turn off. |
| Green LED flashes | The power supply voltage is outside the specified range for your device. It may either be too low or too high. Some unregulated adaptors may produce voltages significantly in excess of their rated values. If the number of devices connected on a single power supply exceeds its current capability, the voltage may drop below the required minimum voltage. You may experience this problem when many motors on a single supply move together. The load may exceed the maximum current available, causing the voltage to drop too low. If you experience this problem with a single device on a single unregulated supply rated at over 300 mA, then the problem is probably that the supply voltage is too high. |
| Turning the potentiometer causes no motion. | You may be at the end of travel. This can happen due to missed steps even if the device does not appear to be fully extended. Turn the knob the other way. If the device makes noise but does not move you may be in a stall condition (especially if the device appears to be fully extended). See "Stall Condition" below. The amber light should blink when turning the knob, if not, try turning the power off and then on again. You may also have set the Target Velocity (command #42) so low that it doesn't produce any visible motion. Try using command #36 to reset the device to default settings and try again. |
| The amber light comes on briefly when sending a command, but the device does not move and does not return codes. | Check baud rate, hand shaking, parity, stop bit, etc. Make sure that your software does not transmit any control characters like line feed, spaces or something else. The device numbers may not be what you think they are. Issue a renumber command, make sure that the computer does not transmit anything else while the devices renumber. Check that you transmit 6 bytes and that the device number and command are valid. If you encounter the problem when trying to control the device with your own software, try using one of the demo programs from our website to verify that the hardware |
| The device does not send replies but otherwise works. | If you encounter the problem when trying to control the device with your own software, try using a demo program from our website to verify that the hardware is functioning properly. Make sure that the receiving part of your code or commercial package is correct. Check baud rate, etc. Check connectors for bent or broken pins. |
| The device sometimes returns fewer than 6 bytes. | This problem usually indicates a problem with the settings for your serial port. Some serial ports are set to automatically recognize and remove specific control characters such as carriage returns when they appear in the RS232 receive buffer. When this happens, it appears as though the device has not sent enough bytes, but really the controlling computer has just removed some before you could read them. You will need to change the serial port settings to fix the problem. |
| Poor repeatability or the device does not extend or retract smoothly or makes louder than normal noise during travel. | You may be skipping steps. When skipping, the device will lose position in increments of 4 full steps (not microsteps). This condition happens if the thrust needed is more than the thrust available from the device. Check that the force on the device is less than the maximum thrust. Check the voltage using the voltage command. Voltage less than the rated or recommended voltage will reduce the device's maximum thrust. Try a slower target velocity (command #42) as stepper motors produce more thrust when moving slowly. Lead screw conditions greatly affect the performance of linear motion devices. Dirt, damaged threads, no grease or too heavy grease will degrade performance and may contribute to a stall. A black residue appears on the lead screw after extended use. This can increase friction and reduce thrust. Clean the screw and re-grease it. In general if you try to move a large payload or have a large static axial load (like lifting something vertically) you will have more problems. For vertical motion the use of a counterweight, spring or rubber band can help reduce the static load and improve the performance of the device. The default value of the acceleration and target velocity are good for small to medium loads and medium |

speeds. For very light loads and higher speeds, or heavy loads at lower speeds, these parameters can be tuned. Trial and error is the best tuning technique.

The device has repeatability errors smaller than 4 full steps.

If you're not skipping steps, friction may still cause some variation when returning to a position. Depending on the exact cause, there are a couple of device modes that can reduce these errors. See the **Set Device Mode command's** sections on the anti-backlash and anti-sticktion routines.

A linear motion device extends and retracts smoothly but will not retract to the home (zero) position.

The device will not retract below what it believes to be the zero position. If the device has missed steps due to a previous stall condition or if the device has been set to an incorrect position, the device may incorrectly believe it is at the zero position. You can solve the problem by issuing the home command, or by turning the device on and off and manually homing it.

The device does not behave as expected when software sends it a series of commands.

It can be challenging to track down problems in a complicated script or other software. In addition to the standard techniques of debugging any software, it's also helpful to see exactly what bytes are being sent and received on the serial port. There are several tools available to display the raw data from a serial port, and stackoverflow.com has a list of some.

For Zaber's policies on warranty and repair, please refer to the **Ordering Policies**.

Standard products

Standard products are any part numbers that do not contain the suffix ENG followed by a 4 digit number. Most, but not all, standard products are listed for sale on our website. All standard Zaber products are backed by a one-month satisfaction guarantee. If you are not satisfied with your purchase, we will refund your payment minus any shipping charges. Goods must be in brand new saleable condition with no marks. Zaber products are guaranteed for one year. During this period Zaber will repair any products with faults due to manufacturing defects, free of charge.

Custom products

Custom products are any part numbers containing the suffix ENG followed by a 4 digit number. Each of these products has been designed for a custom application for a particular customer. Custom products are guaranteed for one year, unless explicitly stated otherwise. During this period Zaber will repair any products with faults due to manufacturing defects, free of charge.

How to return products

Customers with devices in need of return or repair should contact Zaber to obtain an RMA form which must be filled out and sent back to us to receive an RMA number. The RMA form contains instructions for packing and returning the device. The specified RMA number must be included on the shipment to ensure timely processing.

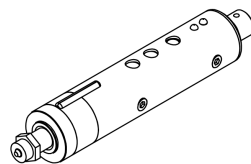
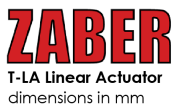
If you would like to receive our periodic email newsletter including product updates and promotions, please sign up online at www.zaber.com (news section). Newsletters typically include a promotional offer worth at least \$100.

Contact Zaber Technologies Inc by any of the following methods:

| | |
|--------------|--|
| Phone | 1-604-569-3780 (direct) 1-888-276-8033 (toll free in North America) |
| Fax | 1-604-648-8033 |
| Mail | #2 - 605 West Kent Ave. N., Vancouver, British Columbia, Canada, V6P 6T7 |
| Web | www.zaber.com |
| Email | Please visit our website for up to date email contact information. |

The original instructions for this product are available at <https://www.zaber.com/manuals/T-LA>.

Please see the **Zaber Support Page** for default settings for this device.

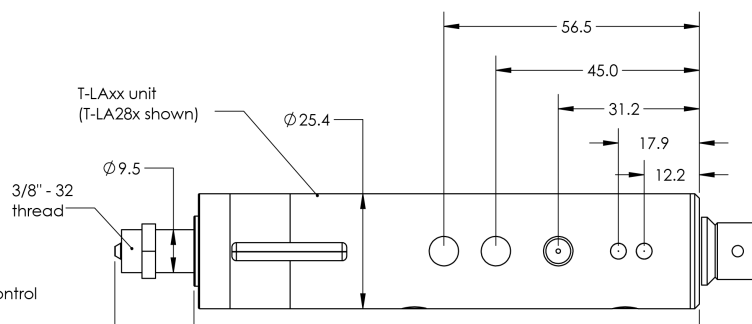


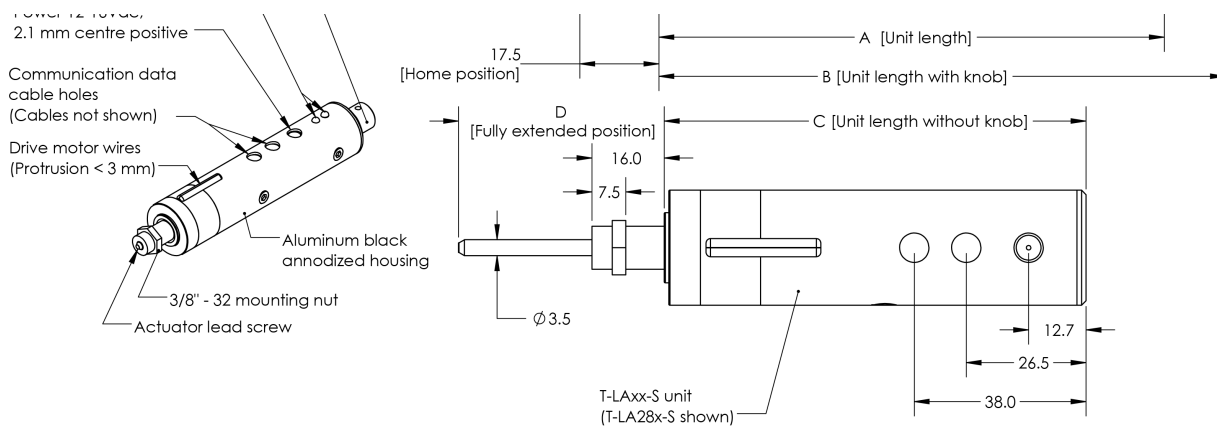
| Model Number* | Travel | A | B | C | D |
|---------------|--------|-------|-------|-------|------|
| T-LA13A | 12.5 | N/A | 125.5 | 111.8 | 30.5 |
| T-LA13A-S | 12.5 | 93.3 | N/A | N/A | 30.5 |
| T-LA28A | 28.0 | N/A | 125.5 | 111.8 | 45.5 |
| T-LA28A-S | 28.0 | 93.3 | N/A | N/A | 45.5 |
| T-LA60A | 59.5 | N/A | 160.5 | 146.8 | 77.5 |
| T-LA60A-S | 59.5 | 128.3 | N/A | N/A | 77.5 |

*See product page for complete list of available models at www.zaber.com

Green & Yellow power status LED (T-LAxx units)
Power 12-16Vdc

Manual knob control (T-LAxx units)





DWG 1015 R01

| Specification | Value | Alternate Unit |
|-------------------------------------|--------------------------|----------------|
| Microstep Size (Default Resolution) | 0.09921875 μm | |
| Built-in Controller | Yes | |
| Repeatability | < 4 μm | < 0.000157" |
| Backlash | < 22 μm | < 0.000866" |
| Maximum Speed | 4 mm/s | 0.157"/s |
| Minimum Speed | 0.0009300 mm/s | 0.000037"/s |
| Speed Resolution | 0.0009300 mm/s | 0.000037"/s |
| Encoder Type | None | |
| Peak Thrust | 25 N | 5.6 lb |
| Maximum Continuous Thrust | 15 N | 3.4 lb |
| Communication Interface | RS-232 | |
| Communication Protocol | Zaber Binary | |
| Maximum Current Draw | 300 mA | |
| Power Supply | 12-16 VDC | |
| Power Plug | 2.1 mm centre positive | |
| Motor Temperature Rise | 75 °C | |
| Linear Motion Per Motor Rev | 0.3048 mm | 0.012" |
| Motor Steps Per Rev | 48 | |
| Motor Type | Stepper (2 phase) | |
| Inductance | 55 mH/phase | |
| Default Resolution | 1/64 of a step | |
| Data Cable Connection | Minidin 6 | |
| Mechanical Drive System | Precision leadscrew | |
| Limit or Home Sensing | Magnetic home sensor | |
| Axes of Motion | 1 | |
| Mounting Interface | 3/8-32 nut or 3/8" shank | |
| Operating Temperature Range | 0 to 50 °C | |
| Vacuum Compatible | No | |
| RoHS Compliant | Yes | |
| CE Compliant | Yes | |

Comparison

| Part Number | Travel Range | Accuracy (unidirectional) | Manual Control | LED Indicators |
|-------------|--------------|---------------------------|----------------|----------------|
|-------------|--------------|---------------------------|----------------|----------------|

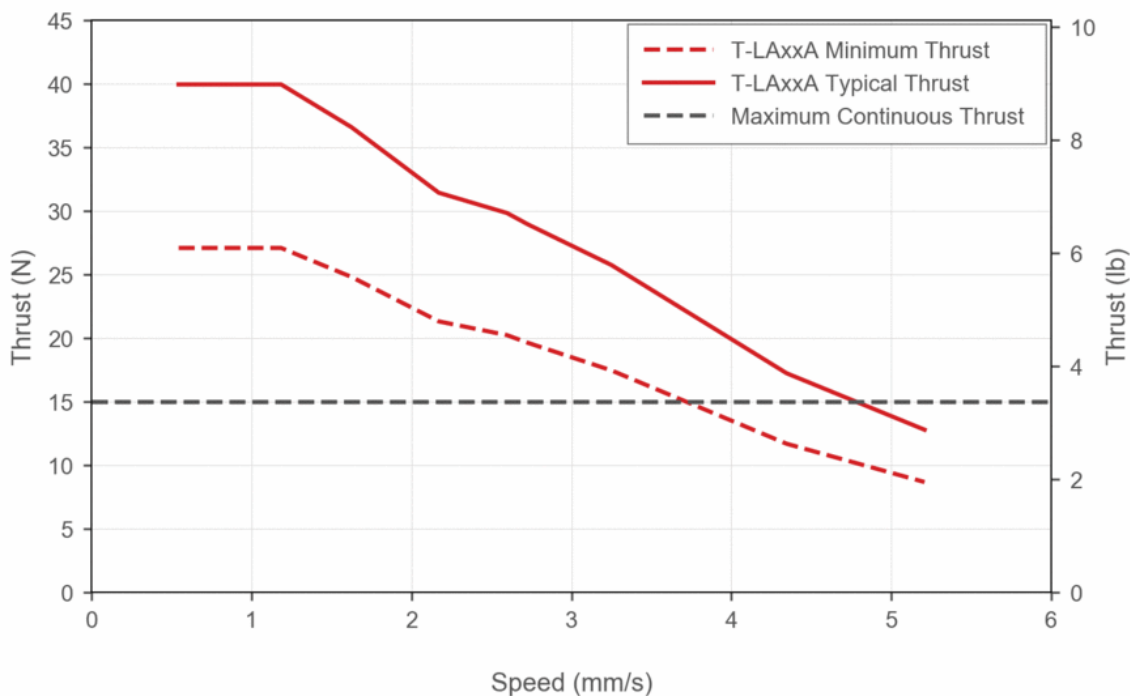
| Part Number | Travel Range | Accuracy (unidirectional) | Manual Control | LED Indicators |
|-------------|----------------|---------------------------|----------------|----------------|
| T-LA13A | 13 mm (0.512") | 24 µm (0.000945") | Yes | Yes |
| T-LA13A-S | 13 mm (0.512") | 24 µm (0.000945") | No | No |
| T-LA28A | 28 mm (1.102") | 24 µm (0.000945") | Yes | Yes |
| T-LA28A-S | 28 mm (1.102") | 24 µm (0.000945") | No | No |
| T-LA60A | 60 mm (2.362") | 36 µm (0.001417") | Yes | Yes |
| T-LA60A-S | 60 mm (2.362") | 36 µm (0.001417") | No | No |

| Part Number | Weight |
|-------------|--------------------|
| T-LA13A | 0.14 kg (0.309 lb) |
| T-LA13A-S | 0.11 kg (0.243 lb) |
| T-LA28A | 0.14 kg (0.309 lb) |
| T-LA28A-S | 0.11 kg (0.243 lb) |
| T-LA60A | 0.15 kg (0.331 lb) |
| T-LA60A-S | 0.14 kg (0.309 lb) |

Charts and Notes

- The suffix "S" designates a short unit. Manual control and LED indicators have been sacrificed on these units in favour of reduced length. All other specifications are identical to the standard unit.
- T-LA actuators don't require hold current to maintain their position.
- The T-LA is more delicate and has a limited lifetime compared to the T-NA08. See the image below for a lifetime vs thrust comparison.

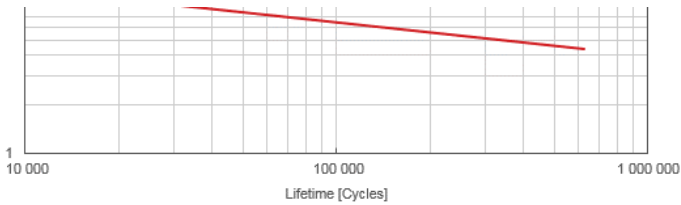
Thrust Speed Performance



T-LA and T-NA Actuator Lifetime at 2.7 mm/s



Note that the failure mode of T-LA devices is grease



contamination by wear particles which effectively clog the lead-nut, although the lead screw and lead-nut remain in healthy condition. Extending the lead screw, cleaning it, and regreasing it with a silicon based grease effectively solves the problem; however, this may not be feasible in all applications. For more detailed information, please consult the [Installation Precautions](#)

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Apéndice D

Circuito integrado AD620.

FEATURES

EASY TO USE

Gain Set with One External Resistor
(Gain Range 1 to 1000)

Wide Power Supply Range (± 2.3 V to ± 18 V)

Higher Performance than Three Op Amp IA Designs

Available in 8-Lead DIP and SOIC Packaging

Low Power, 1.3 mA max Supply Current

EXCELLENT DC PERFORMANCE ("B GRADE")

50 μ V max, Input Offset Voltage

0.6 μ V/ $^{\circ}$ C max, Input Offset Drift

1.0 nA max, Input Bias Current

100 dB min Common-Mode Rejection Ratio (G = 10)

LOW NOISE

9 nV/ $\sqrt{\text{Hz}}$, @ 1 kHz, Input Voltage Noise

0.28 μ V p-p Noise (0.1 Hz to 10 Hz)

EXCELLENT AC SPECIFICATIONS

120 kHz Bandwidth (G = 100)

15 μ s Settling Time to 0.01%

APPLICATIONS

Weigh Scales

ECG and Medical Instrumentation

Transducer Interface

Data Acquisition Systems

Industrial Process Controls

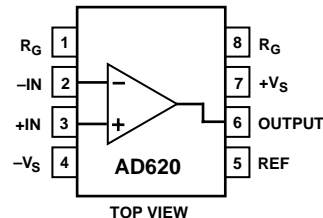
Battery Powered and Portable Equipment

PRODUCT DESCRIPTION

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to

CONNECTION DIAGRAM

8-Lead Plastic Mini-DIP (N), Cerdip (Q)
and SOIC (R) Packages



1000. Furthermore, the AD620 features 8-lead SOIC and DIP packaging that is smaller than discrete designs, and offers lower power (only 1.3 mA max supply current), making it a good fit for battery powered, portable (or remote) applications.

The AD620, with its high accuracy of 40 ppm maximum nonlinearity, low offset voltage of 50 μ V max and offset drift of 0.6 μ V/ $^{\circ}$ C max, is ideal for use in precision data acquisition systems, such as weigh scales and transducer interfaces. Furthermore, the low noise, low input bias current, and low power of the AD620 make it well suited for medical applications such as ECG and noninvasive blood pressure monitors.

The low input bias current of 1.0 nA max is made possible with the use of Super β processing in the input stage. The AD620 works well as a preamplifier due to its low input voltage noise of 9 nV/ $\sqrt{\text{Hz}}$ at 1 kHz, 0.28 μ V p-p in the 0.1 Hz to 10 Hz band, 0.1 pA/ $\sqrt{\text{Hz}}$ input current noise. Also, the AD620 is well suited for multiplexed applications with its settling time of 15 μ s to 0.01% and its cost is low enough to enable designs with one in-amp per channel.

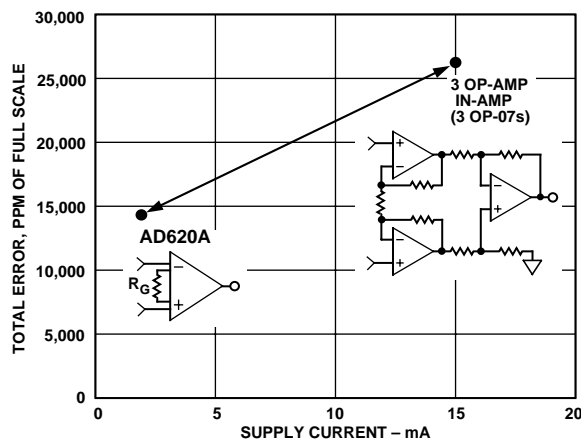


Figure 1. Three Op Amp IA Designs vs. AD620

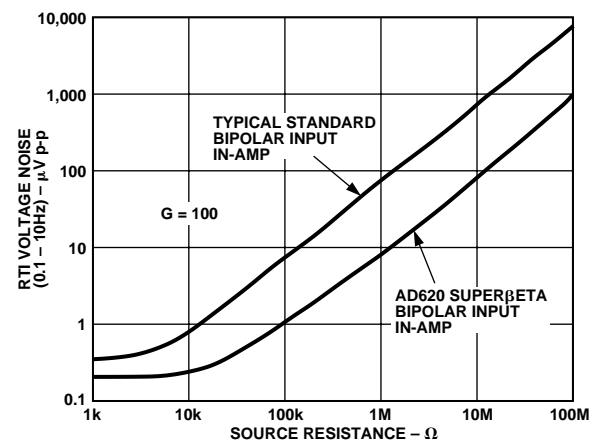


Figure 2. Total Voltage Noise vs. Source Resistance

REV. E

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AD620—SPECIFICATIONS

(Typical @ +25°C, $V_S = \pm 15$ V, and $R_L = 2$ k Ω , unless otherwise noted)

| Model | Conditions | AD620A | | | AD620B | | | AD620S ¹ | | | Units |
|--|---------------------------------|--------------|----------|--------------|--------------|----------|--------------|---------------------|----------|--------------|-----------------|
| | | Min | Typ | Max | Min | Typ | Max | Min | Typ | Max | |
| GAIN | | | | | | | | | | | |
| Gain Range | $G = 1 + (49.4 \text{ k}/R_G)$ | 1 | | 10,000 | 1 | | 10,000 | 1 | | 10,000 | |
| Gain Error ² | $V_{OUT} = \pm 10$ V | | | | | | | | | | |
| G = 1 | | | 0.03 | 0.10 | | 0.01 | 0.02 | | 0.03 | 0.10 | % |
| G = 10 | | | 0.15 | 0.30 | | 0.10 | 0.15 | | 0.15 | 0.30 | % |
| G = 100 | | | 0.15 | 0.30 | | 0.10 | 0.15 | | 0.15 | 0.30 | % |
| G = 1000 | | | 0.40 | 0.70 | | 0.35 | 0.50 | | 0.40 | 0.70 | % |
| Nonlinearity, | $V_{OUT} = -10$ V to $+10$ V, | | | | | | | | | | |
| G = 1–1000 | $R_L = 10$ k Ω | | 10 | 40 | | 10 | 40 | | 10 | 40 | ppm |
| G = 1–100 | $R_L = 2$ k Ω | | 10 | 95 | | 10 | 95 | | 10 | 95 | ppm |
| Gain vs. Temperature | G = 1 | | | 10 | | | 10 | | | 10 | ppm/°C |
| | Gain $>1^2$ | | | –50 | | | –50 | | | –50 | ppm/°C |
| VOLTAGE OFFSET | | | | | | | | | | | |
| (Total RTI Error = $V_{OSI} + V_{OSO}/G$) | | | | | | | | | | | |
| Input Offset, V_{OSI} | $V_S = \pm 5$ V to ± 15 V | | 30 | 125 | | 15 | 50 | | 30 | 125 | μ V |
| Over Temperature | $V_S = \pm 5$ V to ± 15 V | | | 185 | | | 85 | | | 225 | μ V |
| Average TC | $V_S = \pm 5$ V to ± 15 V | | 0.3 | 1.0 | | 0.1 | 0.6 | | 0.3 | 1.0 | μ V/°C |
| Output Offset, V_{OSO} | $V_S = \pm 15$ V | | 400 | 1000 | | 200 | 500 | | 400 | 1000 | μ V |
| Over Temperature | $V_S = \pm 5$ V | | | 1500 | | | 750 | | | 1500 | μ V |
| Average TC | $V_S = \pm 5$ V to ± 15 V | | | 2000 | | | 1000 | | | 2000 | μ V |
| Offset Referred to the Input vs. Supply (PSR) | $V_S = \pm 2.3$ V to ± 18 V | | | | | | | | | | |
| G = 1 | | 80 | | 100 | 80 | | 100 | 80 | | 100 | dB |
| G = 10 | | 95 | | 120 | 100 | | 120 | 95 | | 120 | dB |
| G = 100 | | 110 | | 140 | 120 | | 140 | 110 | | 140 | dB |
| G = 1000 | | 110 | | 140 | 120 | | 140 | 110 | | 140 | dB |
| INPUT CURRENT | | | | | | | | | | | |
| Input Bias Current | | | 0.5 | 2.0 | | 0.5 | 1.0 | | 0.5 | 2 | nA |
| Over Temperature | | | | 2.5 | | | 1.5 | | | 4 | nA |
| Average TC | | | 3.0 | | | 3.0 | | | 8.0 | | pA/°C |
| Input Offset Current | | | 0.3 | 1.0 | | 0.3 | 0.5 | | 0.3 | 1.0 | nA |
| Over Temperature | | | | 1.5 | | | 0.75 | | | 2.0 | nA |
| Average TC | | | 1.5 | | | 1.5 | | | 8.0 | | pA/°C |
| INPUT | | | | | | | | | | | |
| Input Impedance | | | | | | | | | | | |
| Differential | | | 10 2 | | | 10 2 | | | 10 2 | | G Ω pF |
| Common-Mode | | | 10 2 | | | 10 2 | | | 10 2 | | G Ω pF |
| Input Voltage Range ³ | $V_S = \pm 2.3$ V to ± 5 V | $-V_S + 1.9$ | | $+V_S - 1.2$ | $-V_S + 1.9$ | | $+V_S - 1.2$ | $-V_S + 1.9$ | | $+V_S - 1.2$ | V |
| Over Temperature | $V_S = \pm 5$ V to ± 18 V | $-V_S + 2.1$ | | $+V_S - 1.3$ | $-V_S + 2.1$ | | $+V_S - 1.3$ | $-V_S + 2.1$ | | $+V_S - 1.3$ | V |
| Over Temperature | | $-V_S + 1.9$ | | $+V_S - 1.4$ | $-V_S + 1.9$ | | $+V_S - 1.4$ | $-V_S + 1.9$ | | $+V_S - 1.4$ | V |
| Over Temperature | | $-V_S + 2.1$ | | $+V_S - 1.4$ | $-V_S + 2.1$ | | $+V_S - 1.4$ | $-V_S + 2.3$ | | $+V_S - 1.4$ | V |
| Common-Mode Rejection Ratio DC to 60 Hz with 1 k Ω Source Imbalance | $V_{CM} = 0$ V to ± 10 V | | | | | | | | | | |
| G = 1 | | 73 | | 90 | 80 | | 90 | 73 | | 90 | dB |
| G = 10 | | 93 | | 110 | 100 | | 110 | 93 | | 110 | dB |
| G = 100 | | 110 | | 130 | 120 | | 130 | 110 | | 130 | dB |
| G = 1000 | | 110 | | 130 | 120 | | 130 | 110 | | 130 | dB |
| OUTPUT | | | | | | | | | | | |
| Output Swing | $R_L = 10$ k Ω , | | | | | | | | | | |
| Over Temperature | $V_S = \pm 2.3$ V to ± 5 V | $-V_S + 1.1$ | | $+V_S - 1.2$ | $-V_S + 1.1$ | | $+V_S - 1.2$ | $-V_S + 1.1$ | | $+V_S - 1.2$ | V |
| Over Temperature | | $-V_S + 1.4$ | | $+V_S - 1.3$ | $-V_S + 1.4$ | | $+V_S - 1.3$ | $-V_S + 1.6$ | | $+V_S - 1.3$ | V |
| Over Temperature | $V_S = \pm 5$ V to ± 18 V | $-V_S + 1.2$ | | $+V_S - 1.4$ | $-V_S + 1.2$ | | $+V_S - 1.4$ | $-V_S + 1.2$ | | $+V_S - 1.4$ | V |
| Over Temperature | | $-V_S + 1.6$ | | $+V_S - 1.5$ | $-V_S + 1.6$ | | $+V_S - 1.5$ | $-V_S + 2.3$ | | $+V_S - 1.5$ | V |
| Short Current Circuit | | | ± 18 | | | ± 18 | | | ± 18 | | mA |

| Model | Conditions | AD620A | | | AD620B | | | AD620S ¹ | | | Units | |
|---------------------------------|--|--|---------------|------------|---------------|---------------|------------|---------------------|---------------|------------|---------------|--------|
| | | Min | Typ | Max | Min | Typ | Max | Min | Typ | Max | | |
| DYNAMIC RESPONSE | | | | | | | | | | | | |
| Small Signal -3 dB Bandwidth | 10 V Step | | | | | | | | | | | |
| G = 1 | | | 1000 | | | 1000 | | | 1000 | | kHz | |
| G = 10 | | | 800 | | | 800 | | | 800 | | kHz | |
| G = 100 | | | 120 | | | 120 | | | 120 | | kHz | |
| G = 1000 | | | 12 | | | 12 | | | 12 | | kHz | |
| Slew Rate | | | 0.75 | 1.2 | | 0.75 | 1.2 | | 0.75 | 1.2 | V/μs | |
| Settling Time to 0.01% | | | | | | | | | | | | |
| G = 1-100 | | | 15 | | | 15 | | | 15 | μs | | |
| G = 1000 | | | 150 | | | 150 | | | 150 | μs | | |
| NOISE | | | | | | | | | | | | |
| Voltage Noise, 1 kHz | f = 1 kHz | $Total\ RTI\ Noise = \sqrt{(e_{ni}^2) + (e_{no}/G)^2}$ | | | | | | | | | | |
| Input, Voltage Noise, e_{ni} | | | 9 | 13 | | 9 | 13 | | 9 | 13 | nV/√Hz | |
| Output, Voltage Noise, e_{no} | | | 72 | 100 | | 72 | 100 | | 72 | 100 | nV/√Hz | |
| RTI, 0.1 Hz to 10 Hz | | | | | | | | | | | | |
| G = 1 | | | | 3.0 | | | 3.0 | 6.0 | | 3.0 | 6.0 | μV p-p |
| G = 10 | | | | 0.55 | | | 0.55 | 0.8 | | 0.55 | 0.8 | μV p-p |
| G = 100-1000 | | | 0.28 | | | 0.28 | 0.4 | | 0.28 | 0.4 | μV p-p | |
| Current Noise | | | 100 | | | 100 | | | 100 | fA/√Hz | | |
| 0.1 Hz to 10 Hz | | | 10 | | | 10 | | | 10 | pA p-p | | |
| REFERENCE INPUT | | | | | | | | | | | | |
| R_{IN} | $V_{IN+}, V_{REF} = 0$ | | 20 | | | 20 | | | 20 | | kΩ | |
| I_{IN} | | | +50 | +60 | | +50 | +60 | | +50 | +60 | μA | |
| Voltage Range | | | - $V_S + 1.6$ | | + $V_S - 1.6$ | - $V_S + 1.6$ | | + $V_S - 1.6$ | - $V_S + 1.6$ | | + $V_S - 1.6$ | V |
| Gain to Output | | | | 1 ± 0.0001 | | | 1 ± 0.0001 | | | 1 ± 0.0001 | | |
| POWER SUPPLY | | | | | | | | | | | | |
| Operating Range ⁴ | $V_S = \pm 2.3\text{ V to } \pm 18\text{ V}$ | | ±2.3 | | | ±2.3 | | | ±2.3 | | ±18 | V |
| Quiescent Current | | | | 0.9 | 1.3 | | 0.9 | 1.3 | | 0.9 | 1.3 | mA |
| Over Temperature | | | | 1.1 | 1.6 | | 1.1 | 1.6 | | 1.1 | 1.6 | mA |
| TEMPERATURE RANGE | | | | | | | | | | | | |
| For Specified Performance | | | -40 to +85 | | | -40 to +85 | | | -55 to +125 | | °C | |

NOTES

¹See Analog Devices military data sheet for 883B tested specifications.²Does not include effects of external resistor R_G .³One input grounded. $G = 1$.⁴This is defined as the same supply range which is used to specify PSR.

Specifications subject to change without notice.

AD620

ABSOLUTE MAXIMUM RATINGS¹

| | |
|---|-----------------|
| Supply Voltage | ±18 V |
| Internal Power Dissipation ² | 650 mW |
| Input Voltage (Common Mode) | ±V _S |
| Differential Input Voltage | ±25 V |
| Output Short Circuit Duration | Indefinite |
| Storage Temperature Range (Q) | -65°C to +150°C |
| Storage Temperature Range (N, R) | -65°C to +125°C |
| Operating Temperature Range | |
| AD620 (A, B) | -40°C to +85°C |
| AD620 (S) | -55°C to +125°C |
| Lead Temperature Range | |
| (Soldering 10 seconds) | +300°C |

NOTES

¹Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

²Specification is for device in free air:

8-Lead Plastic Package: $\theta_{JA} = 95^{\circ}\text{C}/\text{W}$

8-Lead Cerdip Package: $\theta_{JA} = 110^{\circ}\text{C}/\text{W}$

8-Lead SOIC Package: $\theta_{JA} = 155^{\circ}\text{C}/\text{W}$

ORDERING GUIDE

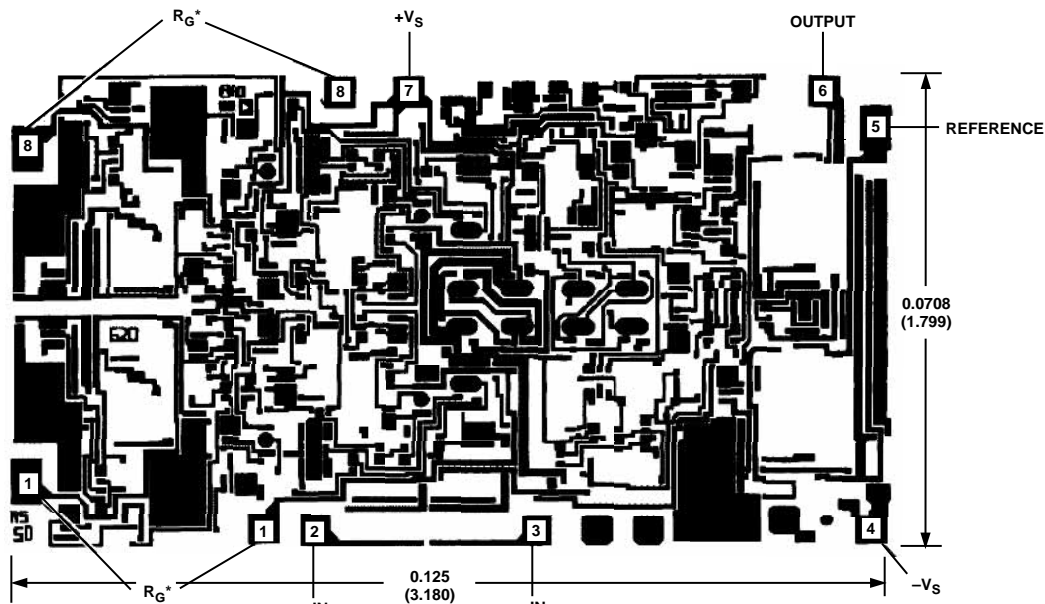
| Model | Temperature Ranges | Package Options* |
|---------------|--------------------|------------------|
| AD620AN | -40°C to +85°C | N-8 |
| AD620BN | -40°C to +85°C | N-8 |
| AD620AR | -40°C to +85°C | SO-8 |
| AD620AR-REEL | -40°C to +85°C | 13" REEL |
| AD620AR-REEL7 | -40°C to +85°C | 7" REEL |
| AD620BR | -40°C to +85°C | SO-8 |
| AD620BR-REEL | -40°C to +85°C | 13" REEL |
| AD620BR-REEL7 | -40°C to +85°C | 7" REEL |
| AD620ACHIPS | -40°C to +85°C | Die Form |
| AD620SQ/883B | -55°C to +125°C | Q-8 |

*N = Plastic DIP; Q = Cerdip; SO = Small Outline.

METALIZATION PHOTOGRAPH

Dimensions shown in inches and (mm).

Contact factory for latest dimensions.



*FOR CHIP APPLICATIONS: THE PADS 1R_G AND 8R_G MUST BE CONNECTED IN PARALLEL TO THE EXTERNAL GAIN REGISTER R_G. DO NOT CONNECT THEM IN SERIES TO R_G. FOR UNITY GAIN APPLICATIONS WHERE R_G IS NOT REQUIRED, THE PADS 1R_G MAY SIMPLY BE BONDED TOGETHER, AS WELL AS THE PADS 8R_G.

CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the AD620 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.



Typical Characteristics (@ +25°C, $V_S = \pm 15\text{ V}$, $R_L = 2\text{ k}\Omega$, unless otherwise noted)

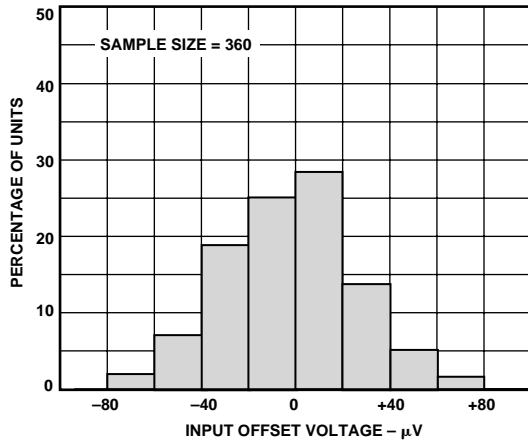


Figure 3. Typical Distribution of Input Offset Voltage

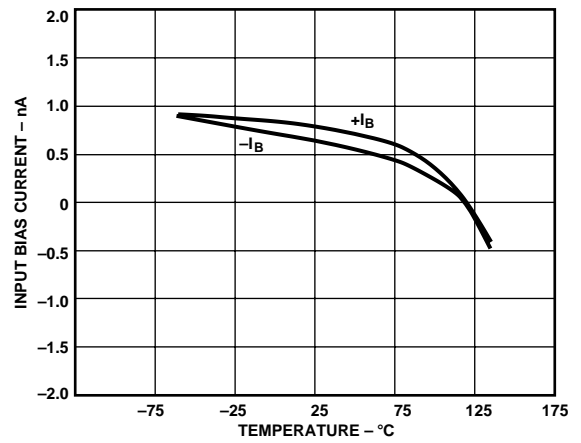


Figure 6. Input Bias Current vs. Temperature

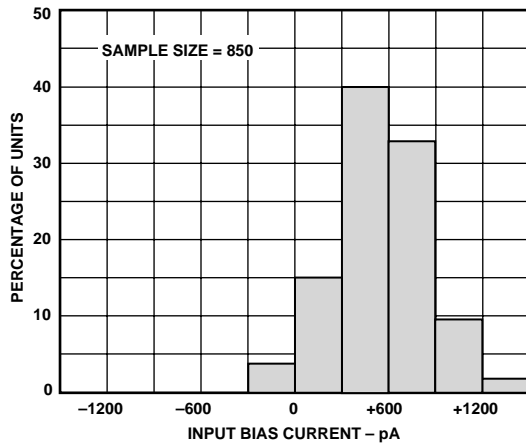


Figure 4. Typical Distribution of Input Bias Current

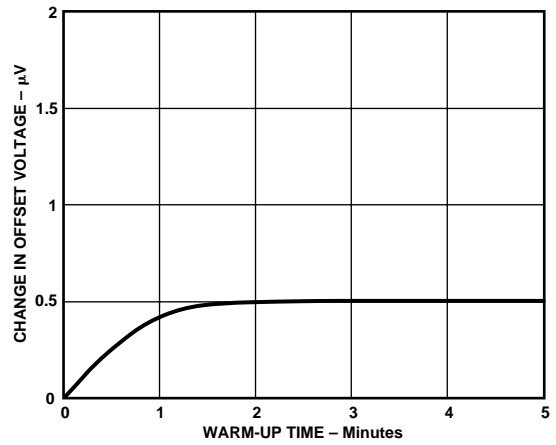


Figure 7. Change in Input Offset Voltage vs. Warm-Up Time

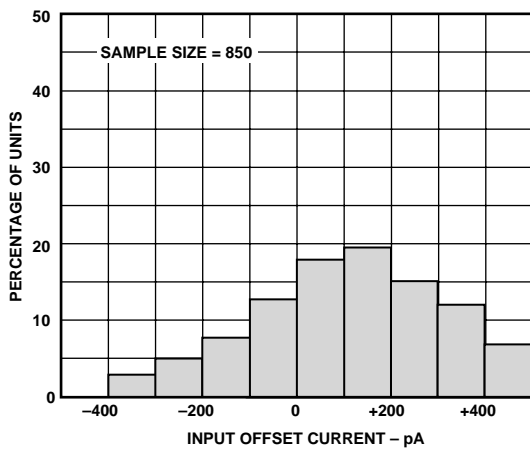


Figure 5. Typical Distribution of Input Offset Current

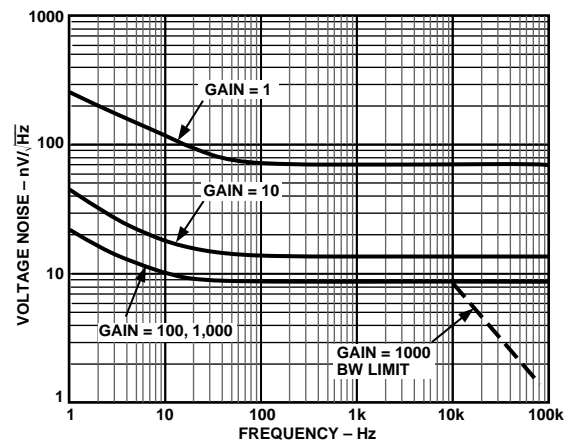


Figure 8. Voltage Noise Spectral Density vs. Frequency, ($G = 1-1000$)

AD620—Typical Characteristics

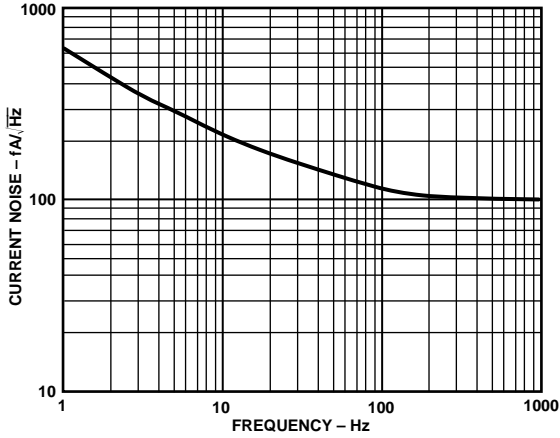


Figure 9. Current Noise Spectral Density vs. Frequency

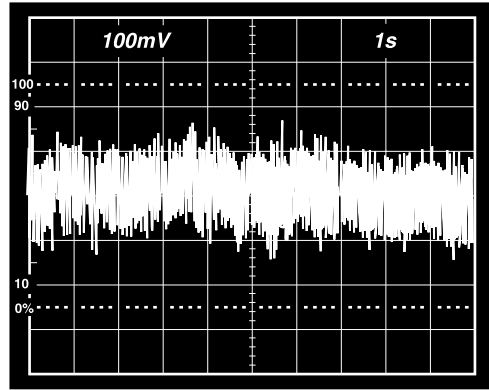


Figure 11. 0.1 Hz to 10 Hz Current Noise, 5 pA/Div

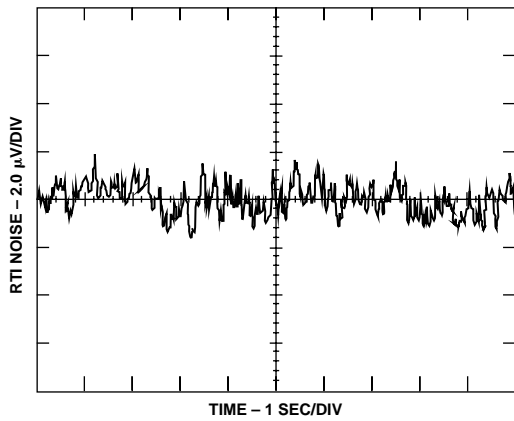


Figure 10a. 0.1 Hz to 10 Hz RTI Voltage Noise ($G = 1$)

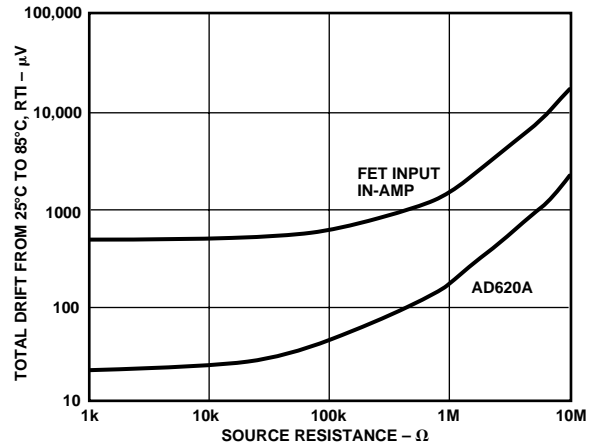


Figure 12. Total Drift vs. Source Resistance

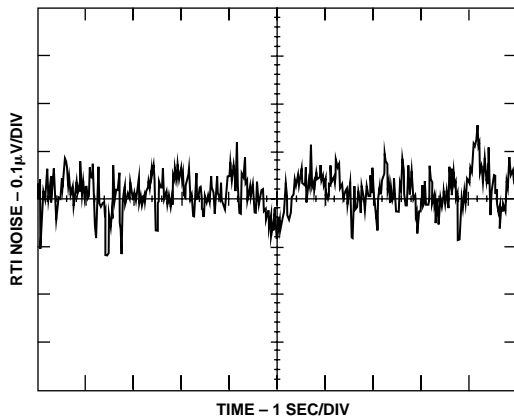


Figure 10b. 0.1 Hz to 10 Hz RTI Voltage Noise ($G = 1000$)

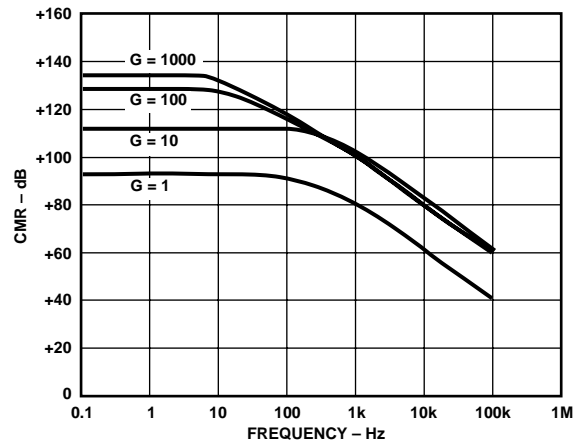


Figure 13. CMR vs. Frequency, RTI, Zero to 1 k Ω Source Imbalance

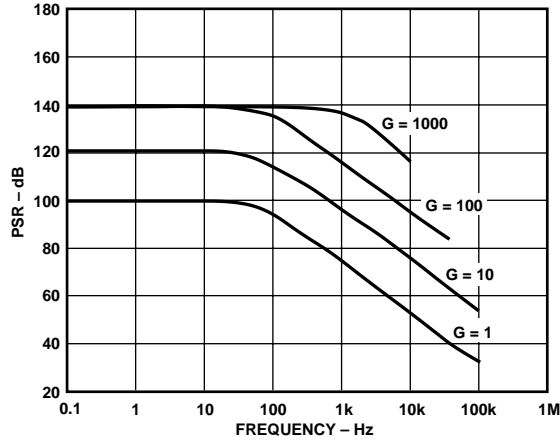


Figure 14. Positive PSR vs. Frequency, RTI ($G = 1-1000$)

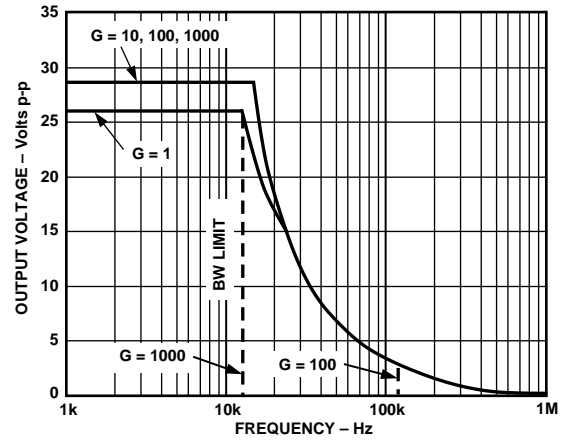


Figure 17. Large Signal Frequency Response

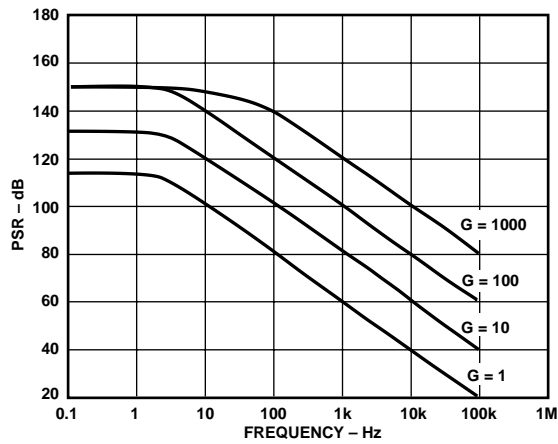


Figure 15. Negative PSR vs. Frequency, RTI ($G = 1-1000$)

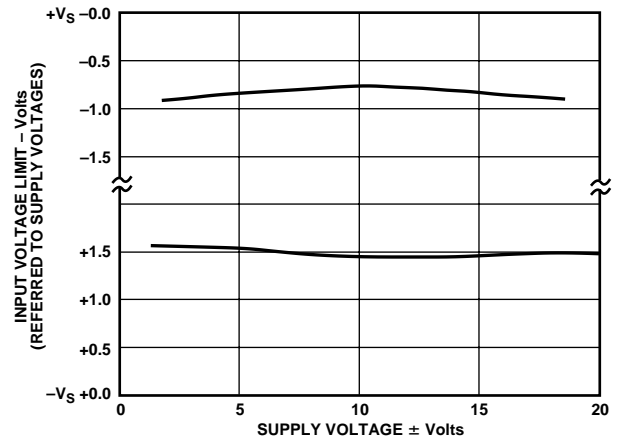


Figure 18. Input Voltage Range vs. Supply Voltage, $G = 1$

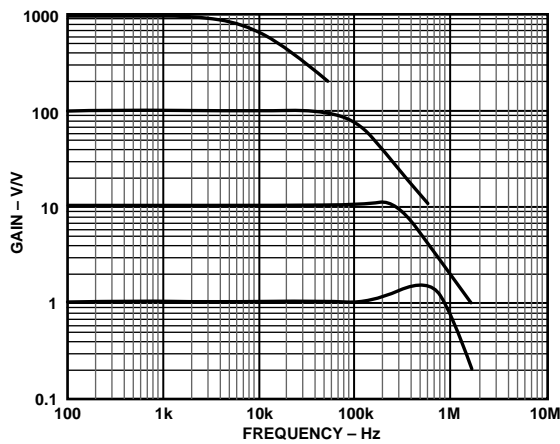


Figure 16. Gain vs. Frequency

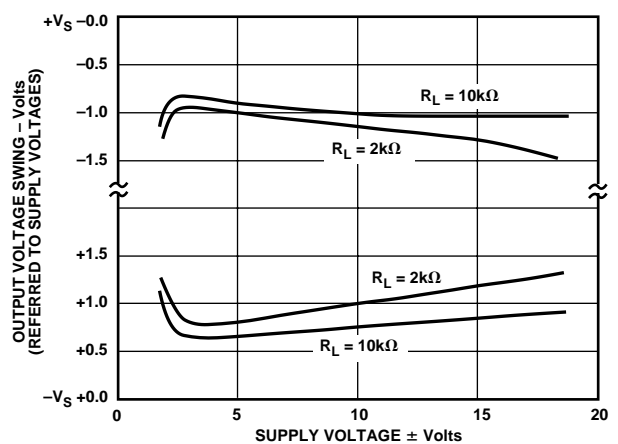


Figure 19. Output Voltage Swing vs. Supply Voltage, $G = 10$

AD620

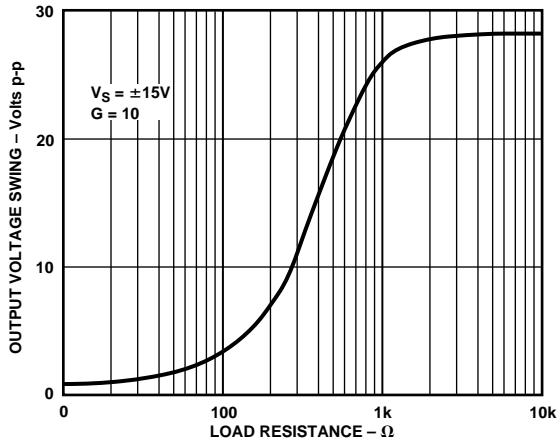


Figure 20. Output Voltage Swing vs. Load Resistance

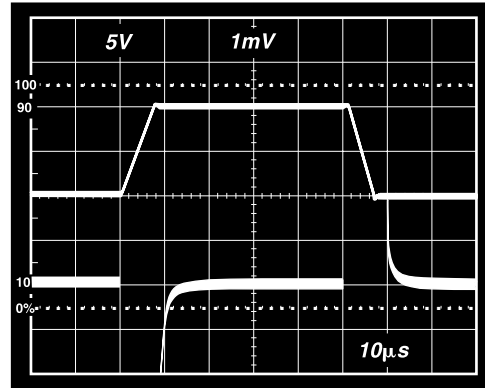


Figure 23. Large Signal Response and Settling Time, $G = 10$ ($0.5 \text{ mV} = 001\%$)

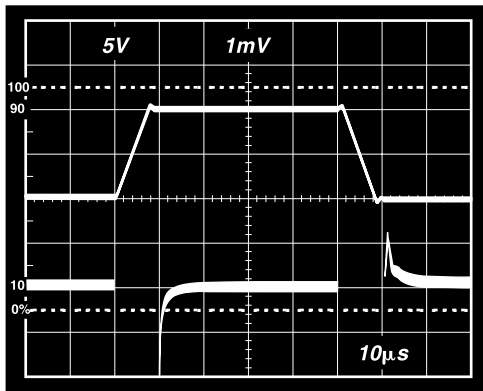


Figure 21. Large Signal Pulse Response and Settling Time $G = 1$ ($0.5 \text{ mV} = 0.01\%$)

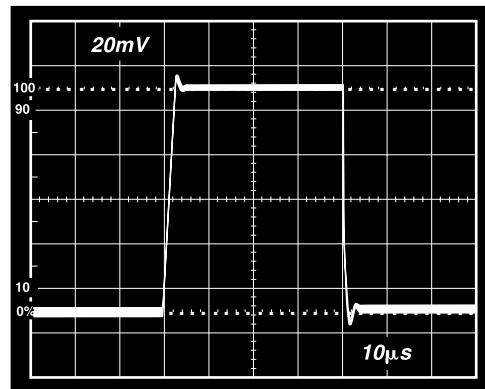


Figure 24. Small Signal Response, $G = 10$, $R_L = 2 \text{ k}\Omega$, $C_L = 100 \text{ pF}$

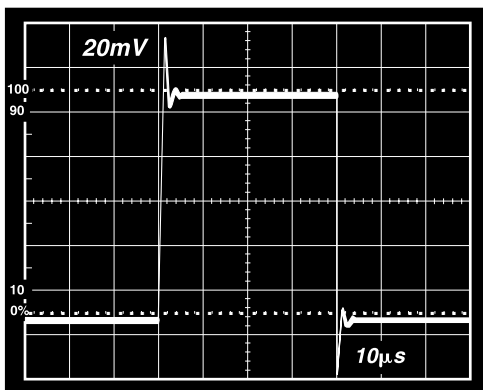


Figure 22. Small Signal Response, $G = 1$, $R_L = 2 \text{ k}\Omega$, $C_L = 100 \text{ pF}$

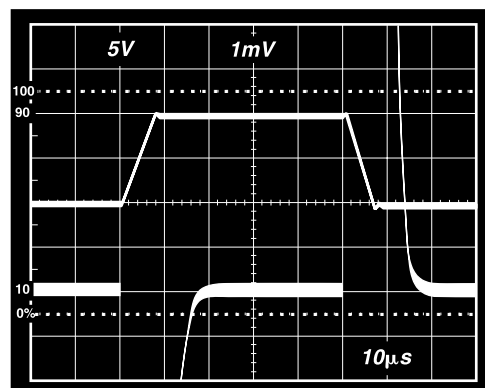


Figure 25. Large Signal Response and Settling Time, $G = 100$ ($0.5 \text{ mV} = 0.01\%$)

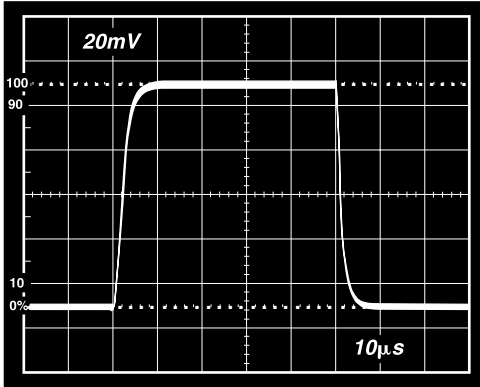


Figure 26. Small Signal Pulse Response, $G = 100$, $R_L = 2\text{ k}\Omega$, $C_L = 100\text{ pF}$

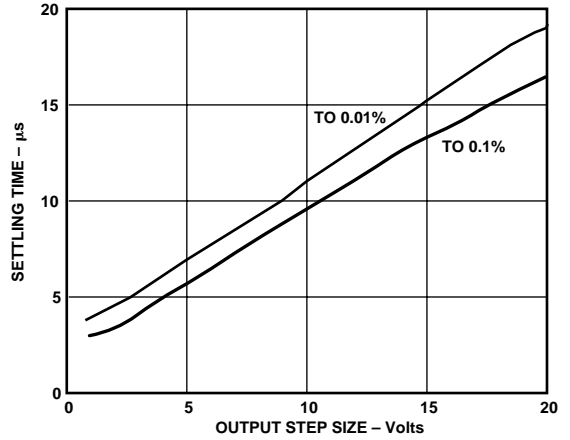


Figure 29. Settling Time vs. Step Size ($G = 1$)

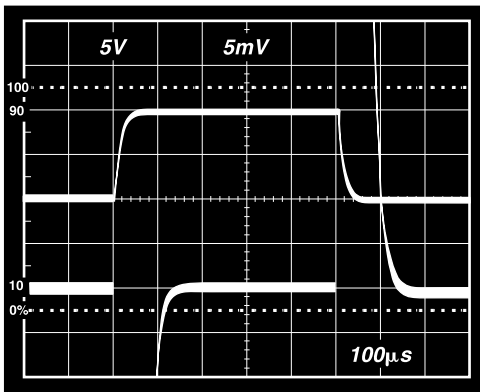


Figure 27. Large Signal Response and Settling Time, $G = 1000$ ($0.5\text{ mV} = 0.01\%$)

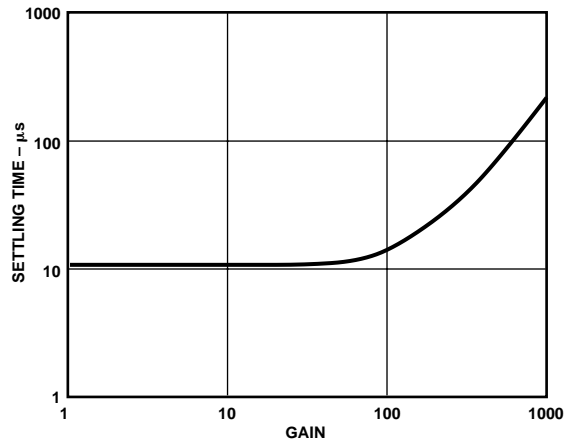


Figure 30. Settling Time to 0.01% vs. Gain, for a 10 V Step

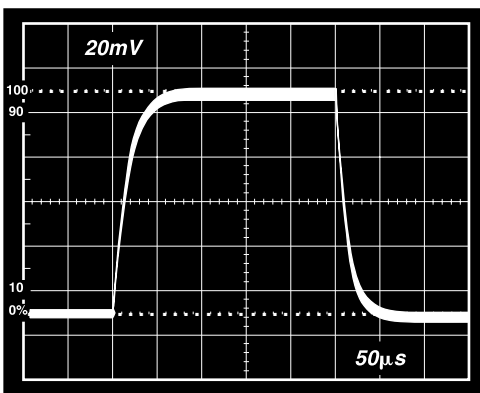


Figure 28. Small Signal Pulse Response, $G = 1000$, $R_L = 2\text{ k}\Omega$, $C_L = 100\text{ pF}$

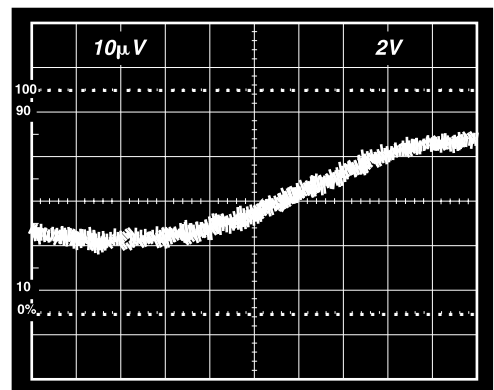


Figure 31a. Gain Nonlinearity, $G = 1$, $R_L = 10\text{ k}\Omega$ ($10\text{ }\mu\text{V} = 1\text{ ppm}$)

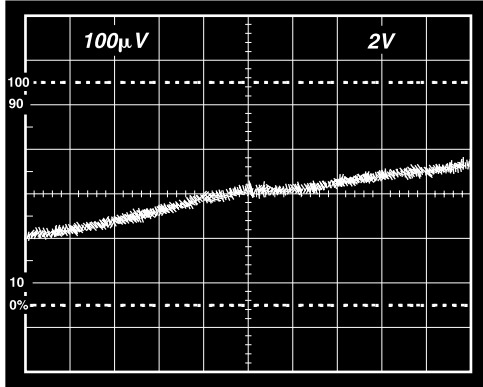


Figure 31b. Gain Nonlinearity, $G = 100$, $R_L = 10\text{ k}\Omega$
($100\text{ }\mu\text{V} = 10\text{ ppm}$)

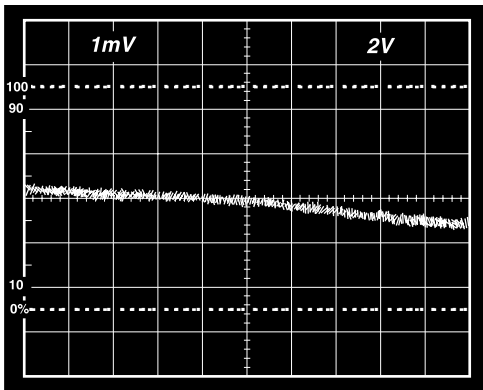


Figure 31c. Gain Nonlinearity, $G = 1000$, $R_L = 10\text{ k}\Omega$
($1\text{ mV} = 100\text{ ppm}$)

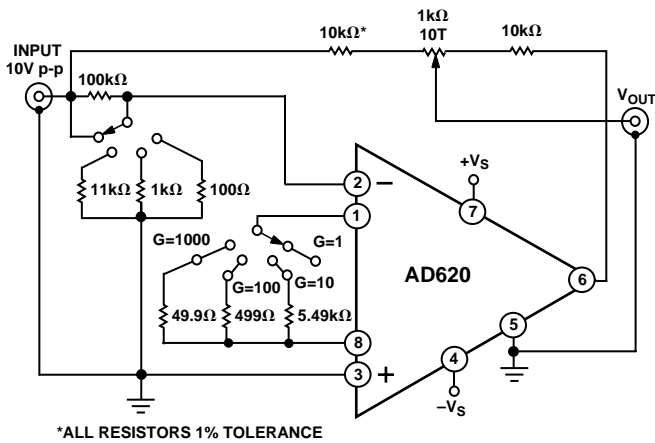


Figure 32. Settling Time Test Circuit

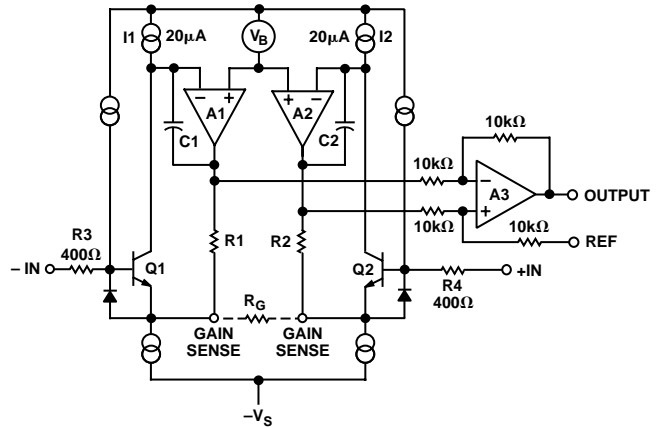


Figure 33. Simplified Schematic of AD620

THEORY OF OPERATION

The AD620 is a monolithic instrumentation amplifier based on a modification of the classic three op amp approach. Absolute value trimming allows the user to program gain *accurately* (to 0.15% at $G = 100$) with only one resistor. Monolithic construction and laser wafer trimming allow the tight matching and tracking of circuit components, thus ensuring the high level of performance inherent in this circuit.

The input transistors Q1 and Q2 provide a single differential-pair bipolar input for high precision (Figure 33), yet offer $10\times$ lower Input Bias Current thanks to Superbeta processing. Feedback through the Q1-A1-R1 loop and the Q2-A2-R2 loop maintains constant collector current of the input devices Q1, Q2 thereby impressing the input voltage across the external gain setting resistor R_G . This creates a differential gain from the inputs to the A1/A2 outputs given by $G = (R1 + R2)/R_G + 1$. The unity-gain subtracter A3 removes any common-mode signal, yielding a single-ended output referred to the REF pin potential.

The value of R_G also determines the transconductance of the preamp stage. As R_G is reduced for larger gains, the transconductance increases asymptotically to that of the input transistors. This has three important advantages: (a) Open-loop gain is boosted for increasing programmed gain, thus reducing gain-related errors. (b) The gain-bandwidth product (determined by C1, C2 and the preamp transconductance) increases with programmed gain, thus optimizing frequency response. (c) The input voltage noise is reduced to a value of $9\text{ nV}/\sqrt{\text{Hz}}$, determined mainly by the collector current and base resistance of the input devices.

The internal gain resistors, R1 and R2, are trimmed to an absolute value of $24.7\text{ k}\Omega$, allowing the gain to be programmed accurately with a single external resistor.

The gain equation is then

$$G = \frac{49.4\text{ k}\Omega}{R_G} + 1$$

so that

$$R_G = \frac{49.4\text{ k}\Omega}{G - 1}$$

Make vs. Buy: A Typical Bridge Application Error Budget

The AD620 offers improved performance over “homebrew” three op amp IA designs, along with smaller size, fewer components and 10× lower supply current. In the typical application, shown in Figure 34, a gain of 100 is required to amplify a bridge output of 20 mV full scale over the industrial temperature range of -40°C to +85°C. The error budget table below shows how to calculate the effect various error sources have on circuit accuracy.

Regardless of the system in which it is being used, the AD620 provides greater accuracy, and at low power and price. In simple

systems, absolute accuracy and drift errors are by far the most significant contributors to error. In more complex systems with an intelligent processor, an autogain/autozero cycle will remove all absolute accuracy and drift errors leaving only the resolution errors of gain nonlinearity and noise, thus allowing full 14-bit accuracy.

Note that for the homebrew circuit, the OP07 specifications for input voltage offset and noise have been multiplied by $\sqrt{2}$. This is because a three op amp type in-amp has two op amps at its inputs, both contributing to the overall input error.

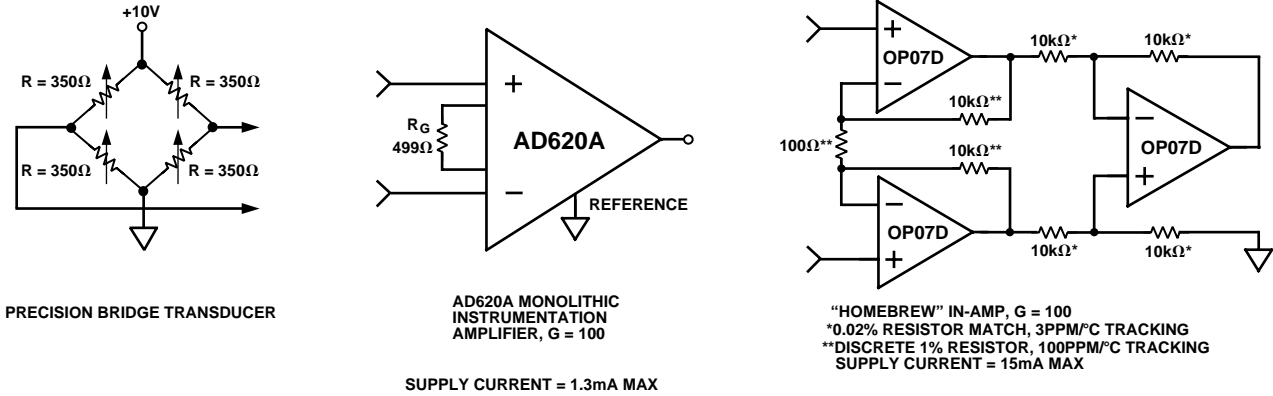


Figure 34. Make vs. Buy

Table I. Make vs. Buy Error Budget

| Error Source | AD620 Circuit Calculation | “Homebrew” Circuit Calculation | Error, ppm of Full Scale | |
|---|---|--|--------------------------|----------|
| | | | AD620 | Homebrew |
| ABSOLUTE ACCURACY at $T_A = +25^\circ\text{C}$ | | | | |
| Input Offset Voltage, μV | 125 $\mu\text{V}/20 \text{ mV}$ | $(150 \mu\text{V} \times \sqrt{2})/20 \text{ mV}$ | 6,250 | 10,607 |
| Output Offset Voltage, μV | 1000 $\mu\text{V}/100/20 \text{ mV}$ | $((150 \mu\text{V} \times 2)/100)/20 \text{ mV}$ | 500 | 150 |
| Input Offset Current, nA | 2 nA $\times 350 \Omega/20 \text{ mV}$ | $(6 \text{ nA} \times 350 \Omega)/20 \text{ mV}$ | 18 | 53 |
| CMR, dB | 110 dB $\rightarrow 3.16 \text{ ppm}, \times 5 \text{ V}/20 \text{ mV}$ | $(0.02\% \text{ Match} \times 5 \text{ V})/20 \text{ mV}/100$ | 791 | 500 |
| DRIFT TO +85°C | | Total Absolute Error | 7,558 | 11,310 |
| Gain Drift, ppm/°C | $(50 \text{ ppm} + 10 \text{ ppm}) \times 60^\circ\text{C}$ | 100 ppm/°C Track $\times 60^\circ\text{C}$ | 3,600 | 6,000 |
| Input Offset Voltage Drift, $\mu\text{V}/^\circ\text{C}$ | 1 $\mu\text{V}/^\circ\text{C} \times 60^\circ\text{C}/20 \text{ mV}$ | $(2.5 \mu\text{V}/^\circ\text{C} \times \sqrt{2} \times 60^\circ\text{C})/20 \text{ mV}$ | 3,000 | 10,607 |
| Output Offset Voltage Drift, $\mu\text{V}/^\circ\text{C}$ | 15 $\mu\text{V}/^\circ\text{C} \times 60^\circ\text{C}/100/20 \text{ mV}$ | $(2.5 \mu\text{V}/^\circ\text{C} \times 2 \times 60^\circ\text{C})/100/20 \text{ mV}$ | 450 | 150 |
| RESOLUTION | | Total Drift Error | 7,050 | 16,757 |
| Gain Nonlinearity, ppm of Full Scale | 40 ppm | 40 ppm | 40 | 40 |
| Typ 0.1 Hz–10 Hz Voltage Noise, $\mu\text{V p-p}$ | 0.28 $\mu\text{V p-p}/20 \text{ mV}$ | $(0.38 \mu\text{V p-p} \times \sqrt{2})/20 \text{ mV}$ | 14 | 27 |
| | | Total Resolution Error | 54 | 67 |
| | | Grand Total Error | 14,662 | 28,134 |

G = 100, $V_S = \pm 15 \text{ V}$.
 (All errors are min/max and referred to input.)

AD620

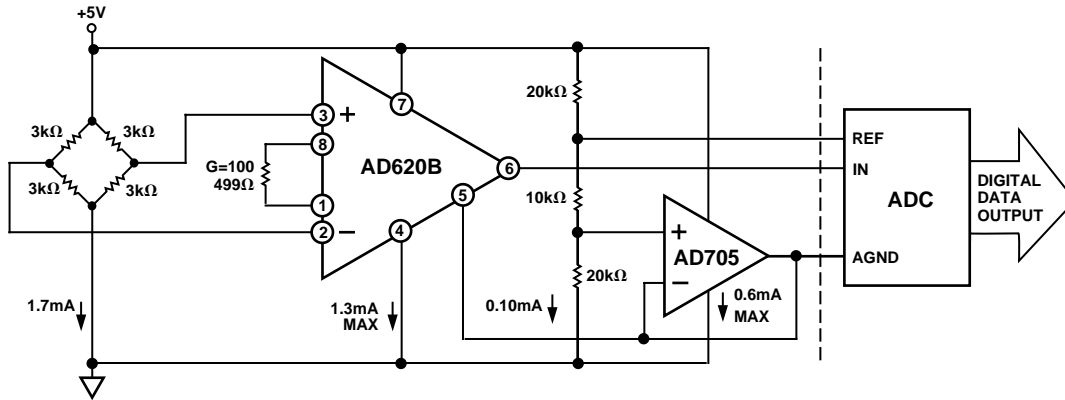


Figure 35. A Pressure Monitor Circuit which Operates on a +5 V Single Supply

Pressure Measurement

Although useful in many bridge applications such as weigh scales, the AD620 is especially suitable for higher resistance pressure sensors powered at lower voltages where small size and low power become more significant.

Figure 35 shows a 3 kΩ pressure transducer bridge powered from +5 V. In such a circuit, the bridge consumes only 1.7 mA. Adding the AD620 and a buffered voltage divider allows the signal to be conditioned for only 3.8 mA of total supply current.

Small size and low cost make the AD620 especially attractive for voltage output pressure transducers. Since it delivers low noise and drift, it will also serve applications such as diagnostic non-invasive blood pressure measurement.

Medical ECG

The low current noise of the AD620 allows its use in ECG monitors (Figure 36) where high source resistances of 1 MΩ or higher are not uncommon. The AD620's low power, low supply voltage requirements, and space-saving 8-lead mini-DIP and SOIC package offerings make it an excellent choice for battery powered data recorders.

Furthermore, the low bias currents and low current noise coupled with the low voltage noise of the AD620 improve the dynamic range for better performance.

The value of capacitor C1 is chosen to maintain stability of the right leg drive loop. Proper safeguards, such as isolation, must be added to this circuit to protect the patient from possible harm.

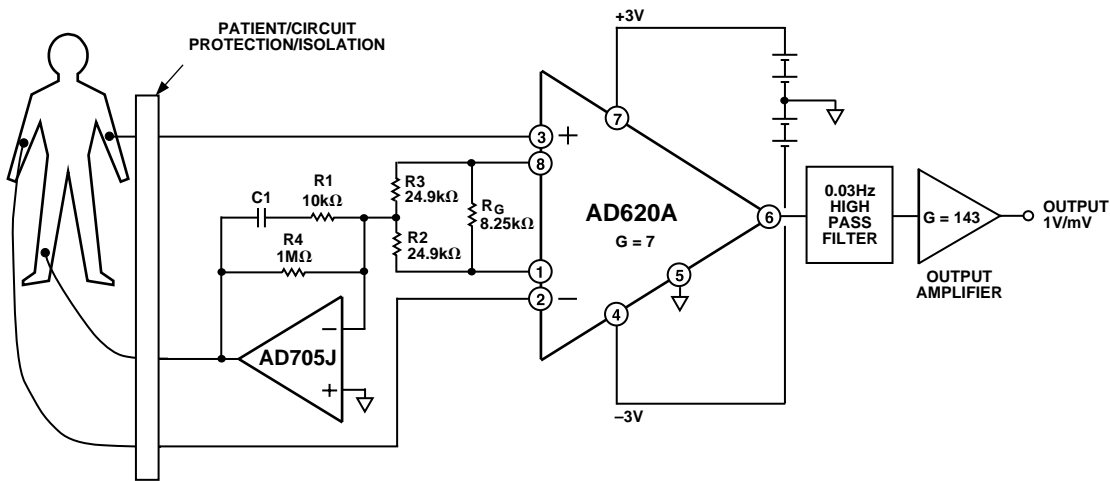


Figure 36. A Medical ECG Monitor Circuit

Precision V-I Converter

The AD620, along with another op amp and two resistors, makes a precision current source (Figure 37). The op amp buffers the reference terminal to maintain good CMR. The output voltage V_X of the AD620 appears across R_1 , which converts it to a current. This current less only, the input bias current of the op amp, then flows out to the load.

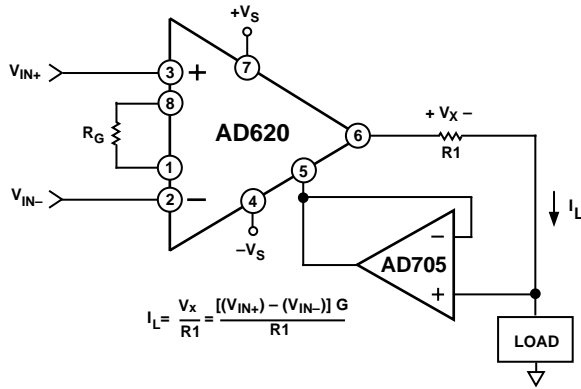


Figure 37. Precision Voltage-to-Current Converter (Operates on 1.8 mA, ±3 V)

GAIN SELECTION

The AD620's gain is resistor programmed by R_G , or more precisely, by whatever impedance appears between Pins 1 and 8. The AD620 is designed to offer accurate gains using 0.1%–1% resistors. Table II shows required values of R_G for various gains. Note that for $G = 1$, the R_G pins are unconnected ($R_G = \infty$). For any arbitrary gain R_G can be calculated by using the formula:

$$R_G = \frac{49.4 \text{ k}\Omega}{G - 1}$$

To minimize gain error, avoid high parasitic resistance in series with R_G ; to minimize gain drift, R_G should have a low TC—less than 10 ppm/°C—for the best performance.

Table II. Required Values of Gain Resistors

| 1% Std Table Value of R_G , Ω | Calculated Gain | 0.1% Std Table Value of R_G , Ω | Calculated Gain |
|--|-----------------|--|-----------------|
| 49.9 k | 1.990 | 49.3 k | 2.002 |
| 12.4 k | 4.984 | 12.4 k | 4.984 |
| 5.49 k | 9.998 | 5.49 k | 9.998 |
| 2.61 k | 19.93 | 2.61 k | 19.93 |
| 1.00 k | 50.40 | 1.01 k | 49.91 |
| 499 | 100.0 | 499 | 100.0 |
| 249 | 199.4 | 249 | 199.4 |
| 100 | 495.0 | 98.8 | 501.0 |
| 49.9 | 991.0 | 49.3 | 1,003 |

INPUT AND OUTPUT OFFSET VOLTAGE

The low errors of the AD620 are attributed to two sources, input and output errors. The output error is divided by G when referred to the input. In practice, the input errors dominate at high gains and the output errors dominate at low gains. The total V_{OS} for a given gain is calculated as:

$$\text{Total Error RTI} = \text{input error} + (\text{output error}/G)$$

$$\text{Total Error RTO} = (\text{input error} \times G) + \text{output error}$$

REFERENCE TERMINAL

The reference terminal potential defines the zero output voltage, and is especially useful when the load does not share a precise ground with the rest of the system. It provides a direct means of injecting a precise offset to the output, with an allowable range of 2 V within the supply voltages. Parasitic resistance should be kept to a minimum for optimum CMR.

INPUT PROTECTION

The AD620 features 400 Ω of series thin film resistance at its inputs, and will safely withstand input overloads of up to ± 15 V or ± 60 mA for several hours. This is true for all gains, and power on and off, which is particularly important since the signal source and amplifier may be powered separately. For longer time periods, the current should not exceed 6 mA ($I_{IN} \leq V_{IN}/400 \Omega$). For input overloads beyond the supplies, clamping the inputs to the supplies (using a low leakage diode such as an FD333) will reduce the required resistance, yielding lower noise.

RF INTERFERENCE

All instrumentation amplifiers can rectify out of band signals, and when amplifying small signals, these rectified voltages act as small dc offset errors. The AD620 allows direct access to the input transistor bases and emitters enabling the user to apply some first order filtering to unwanted RF signals (Figure 38), where $RC \approx 1/(2 \pi f)$ and where $f \geq$ the bandwidth of the AD620; $C \leq 150$ pF. Matching the extraneous capacitance at Pins 1 and 8 and Pins 2 and 3 helps to maintain high CMR.

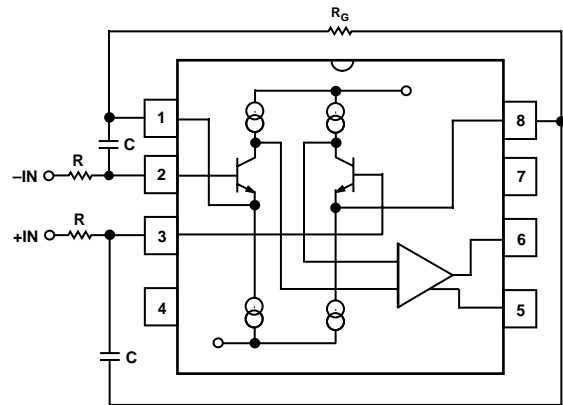


Figure 38. Circuit to Attenuate RF Interference

AD620

COMMON-MODE REJECTION

Instrumentation amplifiers like the AD620 offer high CMR, which is a measure of the change in output voltage when both inputs are changed by equal amounts. These specifications are usually given for a full-range input voltage change and a specified source imbalance.

For optimal CMR the reference terminal should be tied to a low impedance point, and differences in capacitance and resistance should be kept to a minimum between the two inputs. In many applications shielded cables are used to minimize noise, and for best CMR over frequency the shield should be properly driven. Figures 39 and 40 show active data guards that are configured to improve ac common-mode rejections by “bootstrapping” the capacitances of input cable shields, thus minimizing the capacitance mismatch between the inputs.

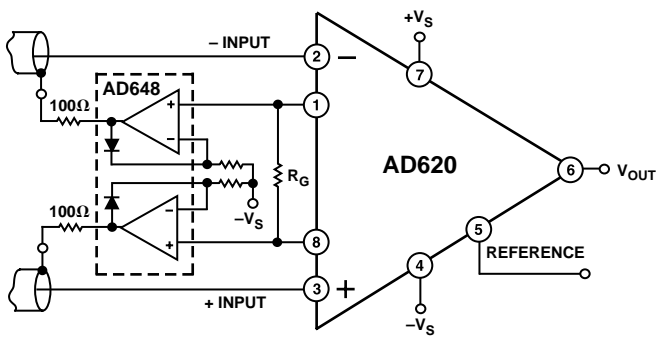


Figure 39. Differential Shield Driver

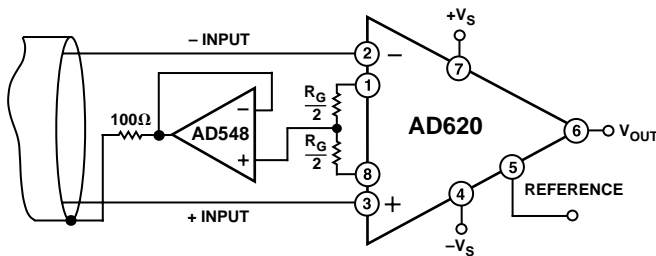


Figure 40. Common-Mode Shield Driver

GROUNDING

Since the AD620 output voltage is developed with respect to the potential on the reference terminal, it can solve many grounding problems by simply tying the REF pin to the appropriate “local ground.”

In order to isolate low level analog signals from a noisy digital environment, many data-acquisition components have separate analog and digital ground pins (Figure 41). It would be convenient to use a single ground line; however, current through ground wires and PC runs of the circuit card can cause hundreds of millivolts of error. Therefore, separate ground returns should be provided to minimize the current flow from the sensitive points to the system ground. These ground returns must be tied together at some point, usually best at the ADC package as shown.

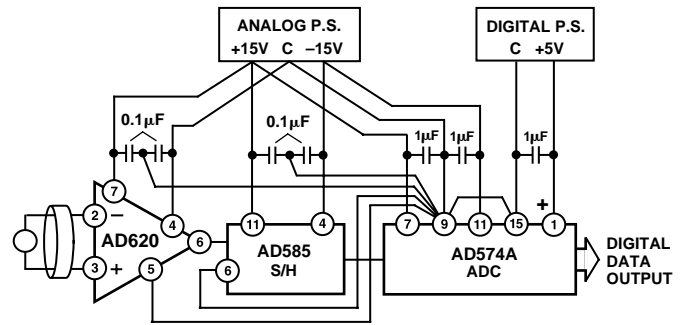


Figure 41. Basic Grounding Practice

GROUND RETURNS FOR INPUT BIAS CURRENTS

Input bias currents are those currents necessary to bias the input transistors of an amplifier. There must be a direct return path for these currents; therefore, when amplifying “floating” input

sources such as transformers, or ac-coupled sources, there must be a dc path from each input to ground as shown in Figure 42. Refer to the *Instrumentation Amplifier Application Guide* (free from Analog Devices) for more information regarding in amp applications.

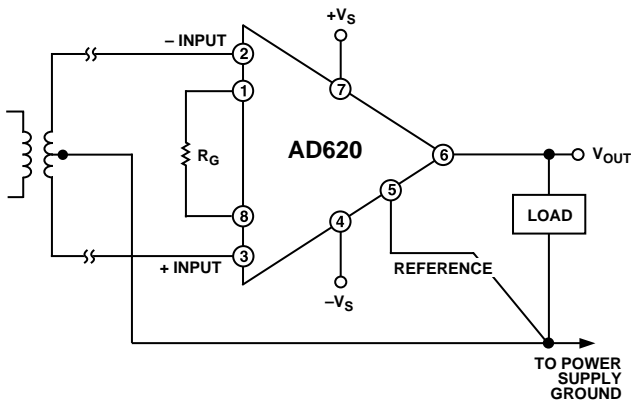


Figure 42a. Ground Returns for Bias Currents with Transformer Coupled Inputs

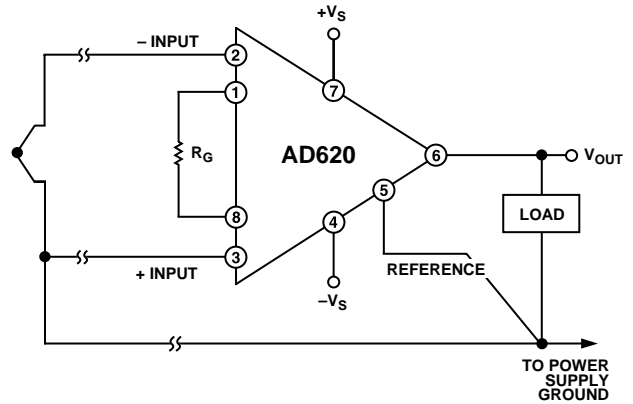


Figure 42b. Ground Returns for Bias Currents with Thermocouple Inputs

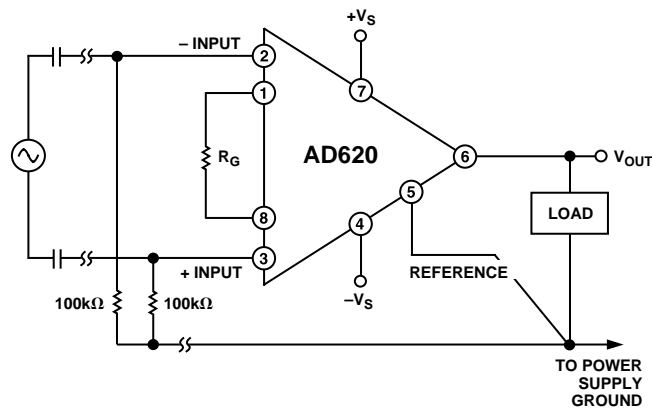
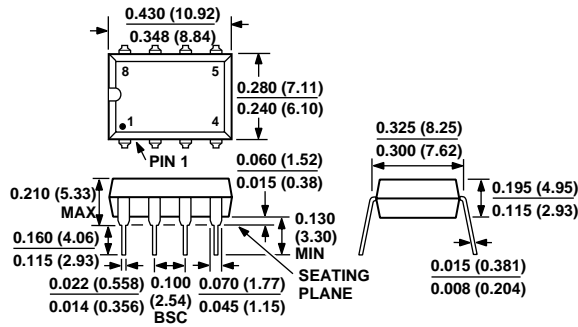


Figure 42c. Ground Returns for Bias Currents with AC Coupled Inputs

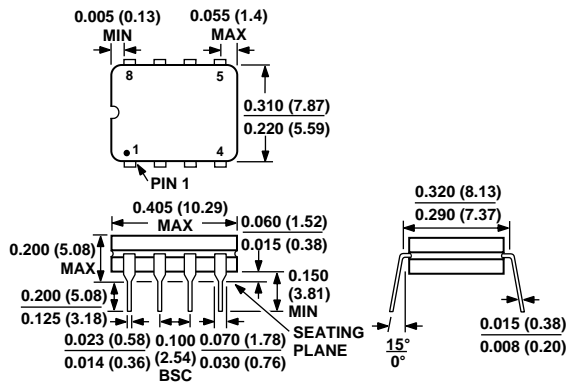
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

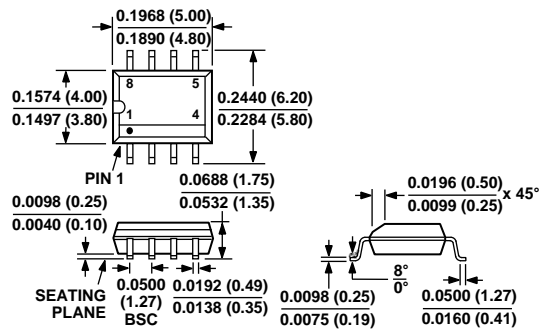
Plastic DIP (N-8) Package



Cerdip (Q-8) Package



SOIC (SO-8) Package



Apéndice E

Tarjeta de adquisición de datos NI-DAQ

USB-6009.

USB-6009 Specifications

Definitions

Warranted specifications describe the performance of a model under stated operating conditions and are covered by the model warranty.

Characteristics describe values that are relevant to the use of the model under stated operating conditions but are not covered by the model warranty.

- **Typical** specifications describe the performance met by a majority of models.
- **Nominal** specifications describe an attribute that is based on design, conformance testing, or supplemental testing.

Specifications are **Typical** unless otherwise noted.

Conditions

Specifications are valid at 25 °C unless otherwise noted.

Analog Input

Analog inputs

| | |
|--------------|------------------------|
| Differential | 4 |
| Single-ended | 8, software-selectable |

Input resolution

| | |
|--------------|---------|
| Differential | 14 bits |
|--------------|---------|

| | |
|------------------------------------|---|
| Single-ended | 13 bits |
| Maximum sample rate (aggregate) | 48 kS/s, system dependent |
| Converter type | Successive approximation |
| AI FIFO | 512 bytes |
| Timing resolution | 41.67 ns (24 MHz timebase) |
| Timing accuracy | 100 ppm of actual sample rate |
| Input range | |
| Differential | $\pm 20\text{ V}$ ^[1] , $\pm 10\text{ V}$, $\pm 5\text{ V}$, $\pm 4\text{ V}$, $\pm 2.5\text{ V}$, $\pm 2\text{ V}$, $\pm 1.25\text{ V}$, $\pm 1\text{ V}$ |
| Single-ended | $\pm 10\text{ V}$ |
| Working voltage | $\pm 10\text{ V}$ |
| Input impedance | 144 k Ω |
| Overvoltage protection | $\pm 35\text{ V}$ |
| Trigger source | Software or external digital trigger |
| System noise ^[2] | |
| Differential | |
| $\pm 20\text{ V}$ range | 5 mV _{rms} |
| $\pm 1\text{ V}$ range | 0.5 mV _{rms} |

Single-ended, ± 10 V range $5 \text{ mV}_{\text{rms}}$

| Range (V) | Typical at 25 °C (mV) | Maximum over Temperature (mV) |
|------------|-----------------------|-------------------------------|
| ± 20 | 14.7 | 138 |
| ± 10 | 7.73 | 84.8 |
| ± 5 | 4.28 | 58.4 |
| ± 4 | 3.59 | 53.1 |
| ± 2.5 | 2.56 | 45.1 |
| ± 2 | 2.21 | 42.5 |
| ± 1.25 | 1.70 | 38.9 |
| ± 1 | 1.53 | 37.5 |

Table 1. Absolute Accuracy at Full Scale, Differential



Note Input voltages may not exceed the working voltage range.

| Range (V) | Typical at 25 °C (mV) | Maximum over Temperature (mV) |
|-----------|-----------------------|-------------------------------|
| ± 10 | 14.7 | 138 |

Table 2. Absolute Accuracy at Full Scale, Single-Ended

Analog Output

| | |
|---------------------|------------------------|
| Analog outputs | 2 |
| Output resolution | 12 bits |
| Maximum update rate | 150 Hz, software-timed |
| Output range | 0 V to +5 V |
| Output impedance | 50 Ω |

| | |
|------------------------------------|--------------|
| Output current drive | 5 mA |
| Power-on state | 0 V |
| Slew rate | 1 V/ μ s |
| Short circuit current | 50 mA |
| Absolute accuracy (no load) | |
| Typical | 7 mV |
| Maximum at full scale | 36.4 mV |

Digital I/O

| | |
|-----------------------------------|--|
| Digital I/O lines | |
| P0.<0..7> | 8 lines |
| P1.<0..3> | 4 lines |
| Direction control | Each channel individually programmable as input or output |
| Output driver type ^[3] | Each channel individually programmable as open collector or active drive |
| Compatibility | TTL, LVTTTL, CMOS |
| Absolute maximum voltage range | -0.5 V to 5.8 V with respect to GND |
| Pull-up resistor | 4.7 k Ω to 5 V |

| Power-on state | Input | |
|---|---------|------------|
| Level | Minimum | Maximum |
| Input low voltage | -0.3 V | 0.8 V |
| Input high voltage | 2.0 V | 5.8 V |
| Input leakage current | — | 50 μ A |
| Output low voltage (I = 8.5 mA) | — | 0.8 V |
| Output high voltage, active drive (I = -8.5 mA) | 2.0 V | 3.5 V |
| Output high voltage, open collector (I = -0.6 mA, nominal) | 2.0 V | 5.0 V |
| Output high voltage, open collector (I = -8.5 mA, with external pull-up resistor) | 2.0 V | — |

Table 3. Digital Logic Levels

External Voltage

| | |
|-------------------------------------|------------------------------|
| +5 V output (200 mA maximum) | |
| Minimum | +4.85 V |
| Typical | +5 V |
| +2.5 V output (1 mA maximum) | +2.5 V |
| +2.5 V accuracy | 0.25% maximum |
| Reference temperature drift | 50 ppm/ $^{\circ}$ C maximum |

Event Counter

| | |
|--------------------|---------|
| Number of counters | 1 |
| Resolution | 32 bits |

| | |
|--------------------------|------------------------------|
| Counter measurements | Edge counting (falling-edge) |
| Counter direction | Count up |
| Pull-up resistor | 4.7 k Ω to 5 V |
| Maximum input frequency | 5 MHz |
| Minimum high pulse width | 100 ns |
| Minimum low pulse width | 100 ns |
| Input high voltage | 2.0 V |
| Input low voltage | 0.8 V |

Bus Interface

| | |
|-------------------|------------------------------|
| USB specification | USB 2.0 full-speed (12 Mb/s) |
|-------------------|------------------------------|

Power Requirements

| | |
|----------------------------------|-------------|
| USB, 4.10 VDC to 5.25 VDC | |
| Typical | 80 mA |
| Maximum | 500 mA |
| USB suspend | |
| Typical | 300 μ A |

| | |
|---------|-------------|
| Maximum | 500 μ A |
|---------|-------------|

Physical Characteristics

Dimensions

| | |
|--------------------|--|
| Without connectors | 63.5 mm \times 85.1 mm \times 23.2 mm (2.50 in. \times 3.35 in. \times 0.91 in.) |
|--------------------|--|

| | |
|-----------------|--|
| With connectors | 81.8 mm \times 85.1 mm \times 23.2 mm (3.22 in. \times 3.35 in. \times 0.91 in.) |
|-----------------|--|

Weight

| | |
|--------------------|---------------|
| Without connectors | 54 g (1.9 oz) |
|--------------------|---------------|

| | |
|-----------------|-------------|
| With connectors | 84 g (3 oz) |
|-----------------|-------------|

| | |
|---------------|-----------------------------|
| USB connector | USB series B receptacle (1) |
|---------------|-----------------------------|

I/O connectors

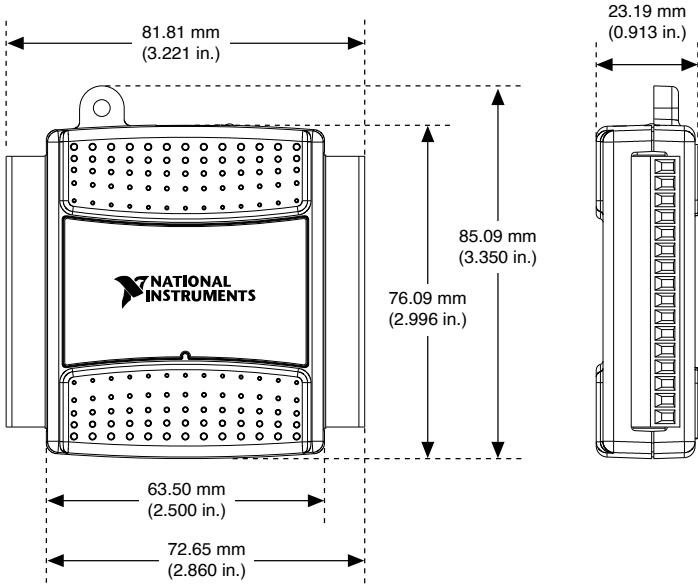
| | |
|------|--------------------------------------|
| Type | 16-position screw terminal plugs (2) |
|------|--------------------------------------|

| | |
|-----------------------|------------------|
| Screw-terminal wiring | 16 AWG to 28 AWG |
|-----------------------|------------------|

| | |
|----------------------------|---|
| Torque for screw terminals | 0.22 N \cdot m to 0.25 N \cdot m (2.0 lb \cdot in. to 2.2 lb \cdot in.) |
|----------------------------|---|

If you need to clean the module, wipe it with a dry towel.

Figure 1. USB-6009 Dimensions





Safety Voltages

Connect only voltages that are within these limits.

| | |
|----------------|-----------------------------------|
| Channel-to-GND | ±30 V max, Measurement Category I |
|----------------|-----------------------------------|

Measurement Category I is for measurements performed on circuits not directly connected to the electrical distribution system referred to as MAINS voltage. MAINS is a hazardous live electrical supply system that powers equipment. This category is for measurements of voltages from specially protected secondary circuits. Such voltage measurements include signal levels, special equipment, limited-energy parts of equipment, circuits powered by regulated low-voltage sources, and electronics

 **Caution** Do not use this module for connection to signals or for measurements within Measurement Categories II, III, or IV

 **Note** Measurement Categories CAT I and CAT O (Other) are equivalent. These test and measurement circuits are not intended for direct

connection to the MAINS building installations of Measurement Categories CAT II, CAT III, or CAT IV.

Environmental

| | |
|--|--------------------------------|
| Temperature (IEC 60068-2-1 and IEC 60068-2-2) | |
| Operating | 0 °C to 55 °C |
| Storage | -40 °C to 85 °C |
| Humidity (IEC 60068-2-56) | |
| Operating | 5% RH to 95% RH, noncondensing |
| Storage | 5% RH to 90% RH, noncondensing |
| Pollution Degree (IEC 60664) | 2 |
| Maximum altitude | 2,000 m |

Indoor use only.

Safety Compliance Standards

This product is designed to meet the requirements of the following electrical equipment safety standards for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA C22.2 No. 61010-1



Note For safety certifications, refer to the product label or the [Product Certifications and Declarations](#) section.

Electromagnetic Compatibility

CE Compliance

This product meets the essential requirements of applicable European Directives, as follows:

- 2014/35/EU; Low-Voltage Directive (safety)
- 2014/30/EU; Electromagnetic Compatibility Directive (EMC)
- 2011/65/EU; Restriction of Hazardous Substances (RoHS)
- 2014/53/EU; Radio Equipment Directive (RED)
- 2014/34/EU; Potentially Explosive Atmospheres (ATEX)

Product Certifications and Declarations

Refer to the product Declaration of Conformity (DoC) for additional regulatory compliance information. To obtain product certifications and the DoC for NI products, visit ni.com/product-certifications, search by model number, and click the appropriate link.

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the **Engineering a Healthy Planet** web page at ni.com/environment. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

Apéndice F

Acondicionador de señal.



ATA-2001

Analog LVDT/RVDT Signal Conditioner with digital calibration

SPECIFICATIONS

- ◆ 115 or 220 VAC line powered
- ◆ Microprocessor controlled calibration
- ◆ Superior digital filtering
- ◆ Selectable excitation frequencies & amplitudes
- ◆ Voltage and current outputs
- ◆ 250 to 1000Hz selectable frequency response
- ◆ Auto fallback synchronization
- ◆ Splash-proof front panel with status LEDs
- ◆ 1/8 DIN standard panel mounting

The ATA-2001 is a general purpose, AC line-powered, LVDT/RVDT analog signal conditioner with digital setup and calibration. The embedded microprocessor generates a PWM-shaped sine wave and handles all calibration functions. It also controls the demodulation, filtration and synchronization of the LVDT or RVDT transducer signal. All settings are stored in non-volatile memory for restoration on power up. Zero, Gain and Phase adjustments are accomplished via the use of splash-proof front panel pushbuttons and digital voltage dividers. Intended for the most demanding industrial applications, the ATA-2001 is CE certified, and has been rigorously tested to the highest industrial standards for EMI, RFI and ESD.

Designed for universal compatibility with 4, 5 and 6 electrical connection transducers, the ATA-2001 provides a wide range of oscillator frequencies, gains and two excitation voltages, affording maximum interface versatility. The very high drive current of 45mA allows operation with transducer input impedances as low as 12 Ohms (with 0.5 VRMS excitation). With high gain capability and low noise, the ATA-2001 provides measurement resolutions beyond most products currently available.

The unique auto fall-back synchronization feature allows reliable master/slave operation, for prevention of amplifier cross talk, without the worry of sync signal loss. If the internal processor in a slave amplifier detects an unstable or missing sync signal, the internal clock will take over, continuing at the pre-selected nominal frequency. Upon restoration of a normal sync pulse, the oscillator will return to the slave mode.

The ATA-2001 is contained within a rugged, one-piece, extruded aluminum housing which provides optimal amplifier performance under the most rigorous EMI and RFI conditions. An integral panel mounting system provides for convenient 1/8 DIN standard, panel installation. A pre-punched 19" rack adapter is also available to accommodate up to eight amplifiers per adapter installation.

FEATURES

- ◆ Microprocessor controlled & non-volatile memory
- ◆ Phase shift compensation
- ◆ Auto fall-back synchronization
- ◆ Rugged extruded aluminum housing

APPLICATIONS

- ◆ Power-gen turbine control
- ◆ Head box slice lip position control
- ◆ Roller gap position feedback
- ◆ Precision metrology labs

PERFORMANCE SPECIFICATIONS

| ELECTRICAL SPECIFICATIONS | |
|--|---|
| Line power requirements | 115VAC $\pm 10\%$, 50-400Hz; 220VAC $\pm 10\%$, 50-400Hz (<i>switch selectable</i>) |
| Line voltage regulation | $\pm 10\%$, with no change in output |
| Voltage output | |
| Unipolar voltage output range | 0 to 10VDC, with 10mA maximum current capability |
| Bipolar voltage output range | ± 10 VDC (using 100% zero suppression), with 10mA maximum current capability |
| Noise and ripple (voltage output) | 3mV RMS maximum @ 2.5KHz excitation frequency |
| Output impedance (voltage output) | 1 Ω maximum |
| Current output | |
| Current output range | 4 to 20mA |
| Internal loop supply voltage | 18VDC |
| Maximum loop resistance | 700 Ω with internal loop supply; 1000 Ω with 24VDC external supply (<i>32vdc MAX</i>) |
| Noise and ripple (current output) | 10 μ A rms (max) |
| Analog outputs frequency response | |
| Frequency response @ -3db | 250Hz @ 2.5kHz excitation 500Hz @ 5.0kHz excitation 1000Hz @ 10kHz excitation |
| Amplifier characteristics | |
| Transducer FSO for 10 VDC output | High gain: 0.04 to 0.9 VRMS; Low gain: 0.5 to 10 VRMS (<i>switch selectable</i>) |
| Input impedance | 100k Ω |
| Zero suppression range | $\pm 110\%$ of FSO |
| Phase shift compensation range | ± 120 degrees maximum |
| Non-linearity and hysteresis | $\pm 0.05\%$ of FSO, maximum |
| Stability | $\pm 0.05\%$ of FSO, maximum, after 20 minute warm up |
| Temperature coefficient of output | $\pm 0.02\%$ of FSO per $^{\circ}$ F [$\pm 0.036\%$ per $^{\circ}$ C] over the operating temperature range |
| Transducer excitation | |
| Voltage | 0.5 or 3.5 VRMS, sine wave (<i>switch selectable</i>) |
| Current | 45mA RMS maximum |
| Frequency | 2.5, 5 or 10kHz (<i>switch selectable</i>) |
| Transducer requirements | |
| Transducer type | LVDT or RVDT with 4, 5 or 6 electrical connections |
| Input impedance (Primary) | 12 Ω minimum with 0.5 VRMS excitation; 80 Ω minimum with 3.5 VRMS excitation |
| Full scale output | High gain: 0.04 to 0.9 VRMS; Low gain: 0.5 to 10 VRMS |

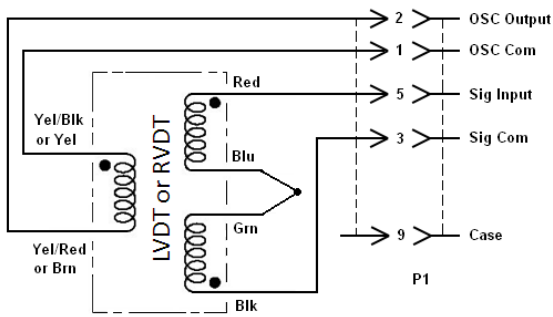
| ENVIRONMENTAL AND MECHANICAL SPECIFICATIONS | |
|---|--|
| Operating temperature range | -40°F to +104°F [-40°C to +40°C] |
| Storage temperature range | -40°F to +257°F [-40°C to +125°C] |
| Weight | 2.1lbs [950 grams] |
| Transducer electrical connections | DB-9S (See our transducer data sheets for jumper cables or connector option) |
| Output and sync connections | Barrier terminal strip |
| Mounting | 1/8 DIN standard panel mounting (19" rack adapter for 8-up available) |
| IEC 60529 rating | IP61 (Front panel only) |

Notes:

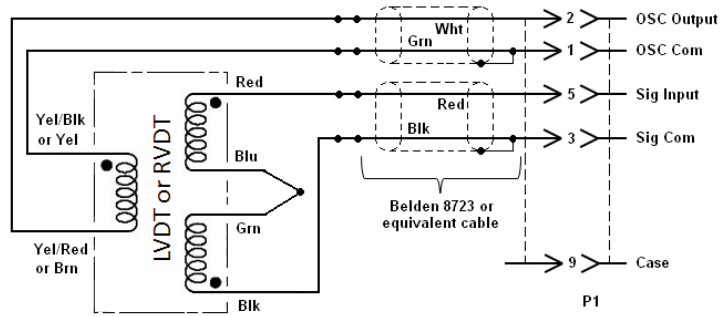
All values are nominal unless otherwise noted

FSO (Full Scale Output) is the largest absolute value of the outputs measured at the range ends

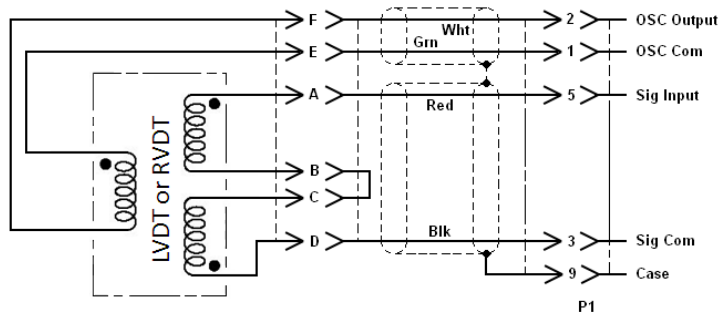
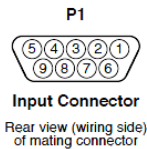
WIRING – INPUT (TRANSDUCER)



TRANSDUCER WITH LEADS OR CABLE

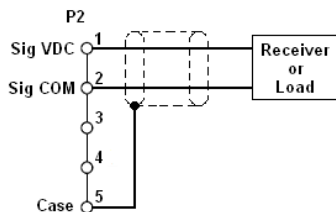


TRANSDUCER WITH LEADS AND SPliced CABLE

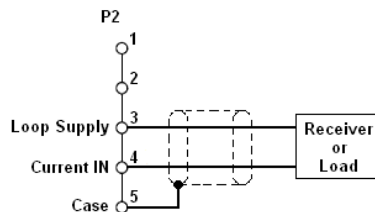


TRANSDUCER WITH CONNECTOR AND JUMPER CABLE

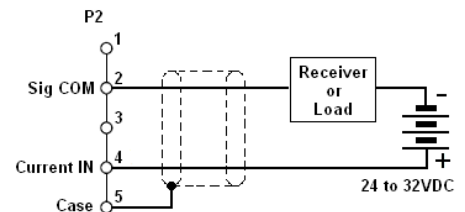
WIRING – OUTPUT



VOLTAGE OUTPUT



4.20mA OUTPUT USING THE INTERNAL LOOP SUPPLY

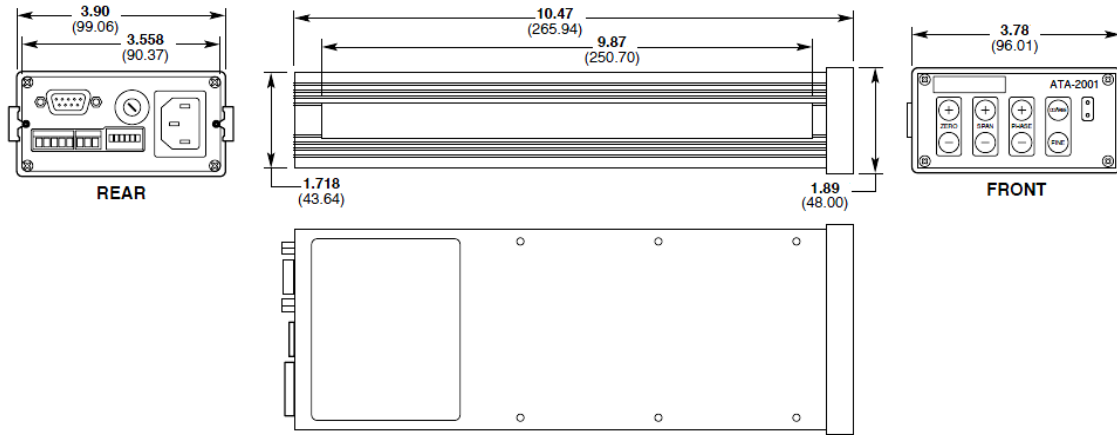


4.20mA OUTPUT USING AN EXTERNAL LOOP SUPPLY

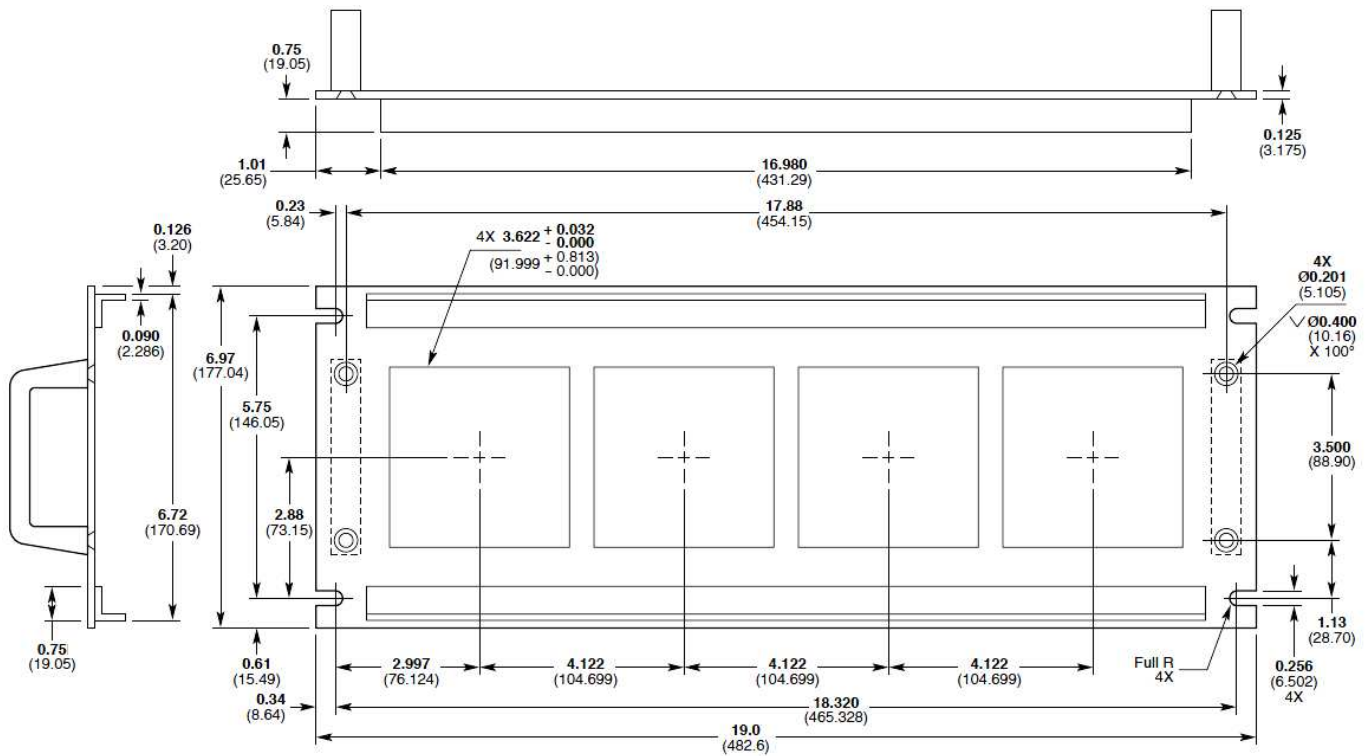
ATA-2001

Analog LVDT/RVDT Signal Conditioner with digital calibration

DIMENSIONS



DIMENSIONS - RACK ADAPTOR (sold separately)



Accommodates up to eight ATA-2001 Amplifiers
Dimensions are in inch (mm)

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