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COARSE ACTUATION SYSTEM – COARSE U-V ACTUATOR LIMIT AND HOME SWITCH POSITIONING

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Abstract

This report describes the procedure used to set both the LIMIT and HOME switches on the coarse U-V actuator sets. Early procedures allowed too much freedom of motion and failed to protect the air bearing from over-travel without relying primarily on the mechanical stops. The mechanical stops are designed to protect the air bearings, but without feedback to the user and control hardware. The changes that were made to the installation procedure reduced the allowable travel without making any sacrifices to the required range of motion. The air bearings are protected from over-travel by the LIMIT switches and the control software provides feedback to the user and control hardware. The assembly procedure used to set up all of the coarse actuator sets is described herein. The LIGO travel requirements and design values are described in great detail as well.

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LIGO PROJECT

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1. Introduction

The Coarse U-V Actuator Assembly of the Coarse Actuator System (CAS) uses optical LIMIT switches to prohibit the CAS from exceeding prescribed motion limits. These limits are necessary due to the limited travel of the air bearing. The DAEDAL tables are capable of moving up to 4" of total travel, however the air bearings are limited to 1.756" of total travel. Mechanical stops were added to the air bearing base as a secondary measure to prevent over-travel, however we cannot rely on the mechanical stops alone. The LIMIT switches provide both a primary interlock to protect the air bearings and other mechanical hardware, as well as provide feedback to the electronics rack and monitoring software.

The LIMIT switches are factory installed in each actuator by DAEDAL and are set to allow maximum travel (4") of the tables. The factory settings exceed CAS travel requirements and must be adjusted to allow full range of motion of the CAS but limit travel to avoid mechanical contact between the air bearing mid-surface and the mechanical stops. HYTEC INC. performs the initial adjustments prior to installation at LIGO Hanford Observatory (LHO) or LIGO Livingston Observatory (LLO). This report encompasses the CAS motion requirements along with the alignment procedure for the LIMIT and HOME switches.

2. CAS Motion Requirements

2.1 Range of Motion Requirements

The CAS has been designed to move the optical platforms in six degrees-of-freedom (DoF). The motions are (refer to Figure 1): 1) along the beamline (UX), 2) transverse to the beamline in the horizontal plane (UY), 3) transverse to the beamline in the vertical plane (UZ), 4) a rotation about the beamline axis (RX) denoted as roll, 5) a rotation about the beamline's transverse axis (RY) denoted as pitch, and 6) a rotation about the vertical axis (RZ) denoted as yaw. These motions will provide alignment corrections for the optical hardware located within the BSC chamber and are expected to occur on a monthly basis when the LIGO system is off-line. The overall required positioning accuracy is not very high, but precision linear actuators will be used to allow free movement in a synchronized fashion without risk of the system binding up.

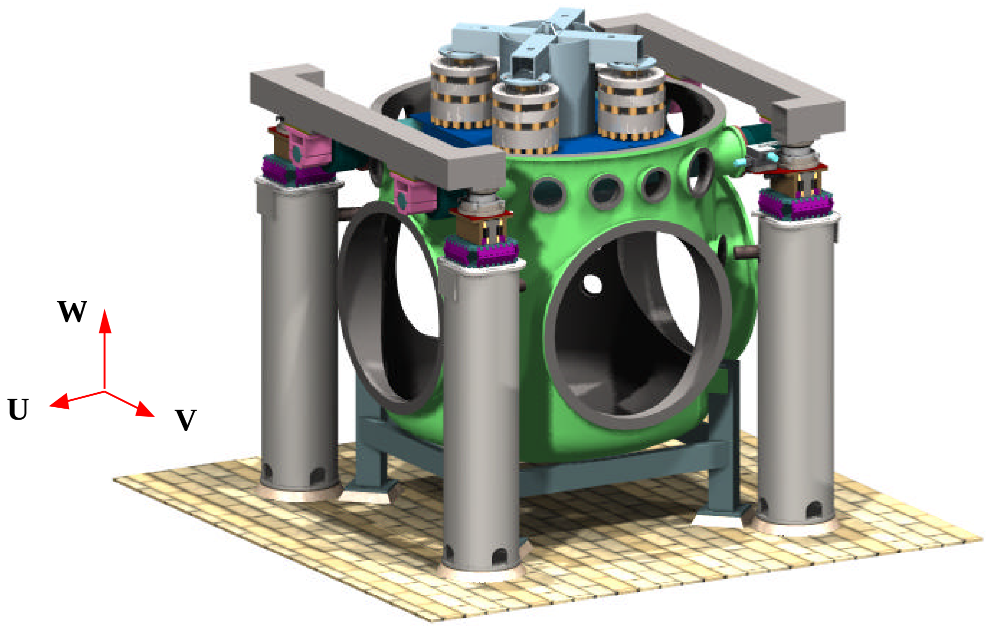

Figure 1. BSC Assembly.

The LIGO Range of Motion requirements for the CAS are given in Table 1.

Table 1. LIGO Range of Motion Requirements.

	Type of Motion	*LIGO Range of Motion*
Translations:	**U – Along Beamline**	±5.0 mm (±0.20 in)
	V – Transverse to Beamline	±5.0 mm (±0.20 in)
	W – Vertical	±5.0 mm (±0.20 in)
Rotations:	**Roll – About U**	±1.50 mrad
	Pitch – About V	±1.50 mrad
	Yaw – About W	±4.00 mrad

The rotations will be performed using linear actuators, therefore each rotational DoF must be transformed into three linear translations. The calculated translations are listed in Table 2.

Table 2. Calculated translations to perform rotations with the CAS.

	U-Translation		*V-Translation*		*W-Translation*	
	± mm	± in	± mm	± in	± mm	± in
Roll:	0	0	1.27	0.05	2.17	0.09
Pitch:	1.27	0.05	0	0	2.17	0.09
Yaw:	5.79	0.23	4.51	0.18	0	0
Total:	**7.07**	**0.28**	**5.79**	**0.23**	**4.34**	**0.17**

The total tranalsations required for full actuation are tabulated in Table 3.

Table 3. CAS Translation Requirements for each Actuator.

	U-Translation		*V-Translation*		*W-Translation*	
	± mm	± in	± mm	± in	± mm	± in
Translations:	5.00	0.20	5.00	0.20	5.00	0.20
Rotations:	7.07	0.28	5.79	0.23	4.34	0.17
Total:	**12.07**	**0.48**	**10.79**	**0.43**	**9.34**	**0.37**

This report encompasses the positioning of the optical LIMIT switches on each of the U and V actuators but does not cover the LIMIT switches on the vertical (W) actuators. Therefore, there will be no further discussions about the W-Translations.

2.2 Allowable Tolerances

The CAS was designed to accommodate both the manufacturing tolerances and the assembly tolerances, in addition to providing the range of motion required by the LIGO specifications. These tolerances were included in the motion design to ensure that the required range of motion is satisfied regardless of the location errors that are inherant in the system. The manufacturing tolerances encompass all of the tolerances that are required to machine each individual piece of CAS hardware. The assembly tolerances are those that are required to assemble and position each piece of hardware on the CAS stack. Table 2.2.1 is a list of both the Assembly and Manufacturing tolerances considered in the CAS motion requirements design. These values can be applied to both the U and V directions.

Table 2.2.1. Assembly and Manufacturing Tolerances on the CAS Stack.

Assembly Tolerances			
Pier Adapter Plate Alignment:			±0.0390
Air Bearing Base Alignment:			±0.0180
Air Bearing Mid-Surface Alignment (RMS):			±0.0286
Includes crossbeam tolerance and air bearing mid-surface centering jig:			
Crossbeam Hole Location	*±0.0060*	*x2*	
Crossbeam Hole Size:	*±0.0180*	*x2*	
Air Bearing Mid-Surface Centering Jig	*±0.0100*		
Total (RMS)	*±0.0286*		
Manufacturing Tolerances			
Pier Adapter Plate Pin Hole Location:			±0.0025
Pier Adapter Plate Pin Hole Size:			±0.0006
Scissors Table Pin Location (Bottom):			±0.0025
Scissors Table Machining Tolerances:			±0.0090
Scissors Table Pin Location (Top):			±0.0025
Fine U-Stage Hole Location:			±0.0000
Fine U-Stage Pin Hole Size:			±0.0007

Fine U-Stage Pin Location:	±0.0025
Air Bearing U-V Mounting Plate Hole Size:	±0.0007
Air Bearing U-V Mounting Plate Pin Hole Location:	±0.0000
Air Bearing U-V Mounting Plate Threaded Bearing Hole Location:	±0.0085
Air Bearing Base Mounting Hole Location:	±0.0060
Mechanical Stop Pin Hole Location:	±0.0100
Air Bearing Mid-Surface Diameter:	±0.0300
Total (RMS):	**±0.0623**

The Root-Mean-Square (RMS) value is used to account for the random behavior of the tolerance stack-up during assembly and machining, and to avoid being ultra-conservative with the CAS design.

2.3 CAS Design Range of Motion Required

The Range of Motion Requirements specified in section 2.1 can be combined with the Assembly and Manufacturing tolerances to come up with a valid design value used in the CAS design. This design value is summarized in Table 2.3.1, which lists the minimum range of motion design values used by HYTEC Inc. in the CAS design.

Table 2.3.1. CAS Range of Motion Design Goal Values.

	U-Translation		***V-Translation***	
	± mm	± in	± mm	± in
LIGO Range of Motion:	12.07	0.480	10.79	0.430
Assembly and Manufacturing Tolerances:	1.58	0.062	1.58	0.062
Total	**13.65**	**0.542**	**12.37**	**0.492**

3. CAS Available Motion

3.1 Air Bearing Travel Setting

The optical LIMIT switches are used as the primary interlock to constrain the air bearing travel. This gives the freedom to decide between two options for setting the LIMIT switches that will provide the greatest amount of travel flexibility. The LIMIT switches can be set to allow complete freedom about the air bearing base surface, allowing it to travel anywhere within the mechanical stop limits (configuration #1). The downside to this is that the mechanical stops will become the primary interlock to limit air bearing travel and feedback to the user will be nonexistant. Figure 3.1.1 illustrates the air bearing range of travel when the mechanical stops are used as the primary interlock. The LIMIT switches allow travel beyond the feasible limits of the air bearing, thereby rendering them useless. A lack of understanding for the CAS could result in a catastrophic failure of one or more of the CAS components when configured in this manner. Therefore, this configuration is highly discouraged and not recommeded by HYTEC Inc.

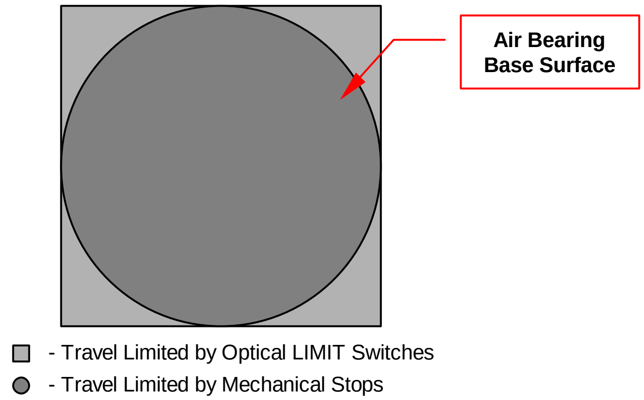

Figure 3.1.1. Air Bearing range of travel with the mechanical stops as the primary interlock.

The recommended configuration (configuration #2) uses the optical LIMIT switches as the primary interlock and allows feedback to the user and control hardware. The mechanical stops are used as a safety measure when a failure occurs in the optical LIMIT switches only. This configuration provides the most protection and feedback, and has become the configuration adopted by HYTEC Inc. and used in the CAS. Figure 3.1.2 illustrates the allowable travel for this configuration. The optical LIMIT switches can easily be set by moving the air bearing to the mechanical stops located at the -45° position and again at the +135° position to secure the +U & +V LIMIT switches, then –U & –V LIMIT switches, respectively. The LIMIT switch positioning is discussed in detail in section 4.0.

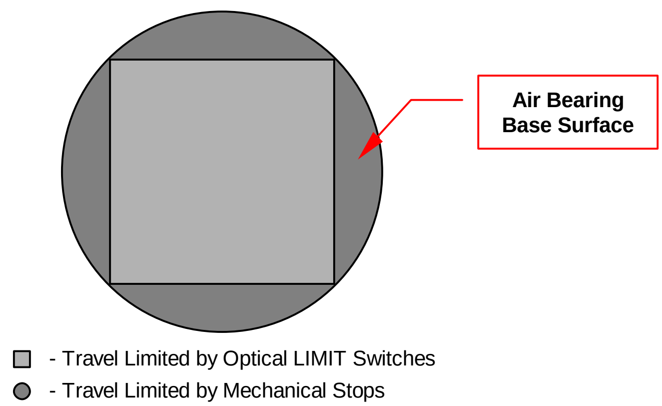

Figure 3.1.2. Air Bearing range of travel with the optical LIMIT switches as the primary interlock.

3.2 Available Air Bearing Travel

The Air Bearing was designed with two limiting conditions. The Air Bearing travel must be limited to prevent interference between the support tube and support tube nozzle port. The air bearing travel must also have enough range to satisfy section 2.3 requirements. It was determined that a nominal travel diameter of 7/8” would satisfy both limiting conditions and was incorporated into the air bearing design. Here, travel diameter represents a diameter about the true center of the air bearing base to which the true center of the air bearing mid-surface can travel within.

The actual travel diameter must be calculated, taking into account such things as the mechanical stop pin diameter, protective rubber bumper thickness and related tolerances. The following is a list of the values used to calculate the actual travel on the air bearing:

Radius of the Air Bearing Base (To mechanical stop pins)	6.000 in
Radius of Air Bearing Mid-Surface:	-5.000 in
Radius of the Mechanical Stop Pin:	-0.125 in
Protective Rubber Bumper Thickness:	-0.025 in
Positional Tolerance of the Pin Location:	-0.010 in
Tolerance of the Air Bearing Mid-Surface Diameter:	-0.015 in
Total Travel	**±0.825 in**

There is also an additional ±0.053 in. of "Bonus" travel that is inherent in the design of the air bearing. Eight mechanical stop pins are used to secure the air bearing mid-surface to the air bearing base. The space between each mechanical stop is large enough to allow the air bearing to travel further than the radius of the mechanical stops. This additional travel can be used when travel extends between two mechanical stops, as illustrated in Figure 3.2.1. This travel is limited to the +0°, ±45°and +90° axes. The bonus travel goes to zero when the air bearing homes in a direction towards a mechanical stop.

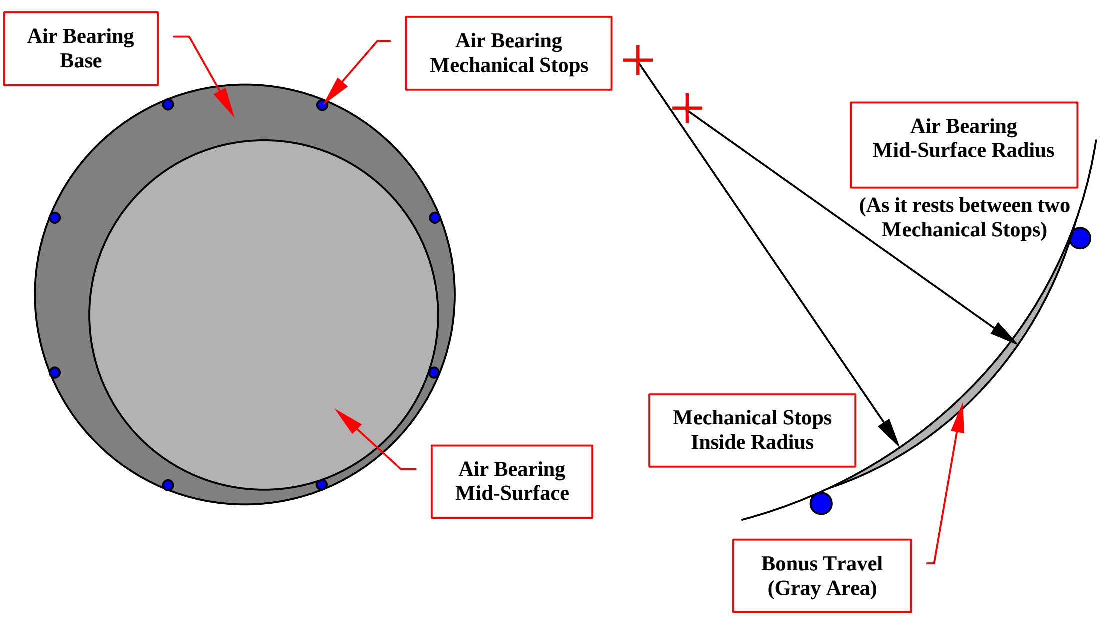

Figure 3.2.1. Air Bearing Top View – This illustrates the bonus travel that is a direct result of the mechanical stop position.

Fortunately this bonus travel can be included in the allowable travel when configuration #2 is used. The reason for this is because the allowable travel is limited by the maximum travel along the ±45° axes. This is **±0.878 in.** when the bonus travel is included. The travel along the X and Y axes will therefore be limited to 0.878" * sin(45°) and 0.878" * cos(45°), respectively. The mechanical stops will never limit the air bearing travel or be used to stop the air bearing unless an electrical failure (holding the LIMIT switch in the OK position) occurs.

4. LIMIT and HOME Switch Alignment Procedure

The following sections briefly outline the procedure used to align and position the optical LIMIT and HOME switches. It has been shown that the alignment is not extremely critical because there is plenty of available tolerance for this alignment procedure.

4.1 Actuator Setup and Alignment

Two Daedal actuators (P/N: 406004LN-ES-D1L2C2M1E1W1 and 406004LN-ES-D1L2C2M1E1W1) mounted on the spacer block (D972105-1) are combined to make up the actuator sets used on the Coarse X-Y Driven Translation Assembly (D972102) as part of the CAS. A total of 18 actuator sets are used in the two LIGO facilities and will provide the horizontal actuation for 15 BSC chambers.

Before assembling the actuator sets, remove the critical screws that hold the actuator side panel to the actuator and will be hidden after assembly. This is only necessary for the side panels that provide side access to the optical LIMIT switches. The U actuator requires that the middle and end screws (furthest from the motor) be removed and the V actuator requires that only the middle screw be removed. Removing these screws at this time will avoid having to disassemble the actuator set in order to remove the side panel later. It is not necessary to completely remove the side panels at this time.

Each of the original 18 actuator sets was pre-assembled at HYTEC Inc. and aligned by Hand Precision. The U-actuator (with NEMA 23 motor flange) is mounted on the spacer block and aligned parallel to the air bearing mounting plate alignment pin locations to within 30 arcsec. The V-actuator (with NEMA 34 motor flange) is cross-mounted and aligned perpendicular to the U-actuator to within 30 arcsec. The actuators were secured together, along with the spacer block, using ¼x20 bolts and roll pins to ensure the alignment is maintained. Each individual actuator becomes a unique part of the actuator set once match drilled and can not be interchanged with other actuators unless the actuator sets are realigned and match drilled. The actuator set can be moved from one BSC to another as a unit.

4.2 Course U-V Actuator Assembly

A jig was used at HYTEC Inc. to position each actuator set within a laboratory environment. Bench-top alignment can be performed with greater ease and accuracy versus aligning the optical limit switches while positioned on the BSC piers. An air bearing (D972106-1) is required in the assembly procedure and the prototype air bearing was used as part of HYTEC Inc.'s alignment setup.

Place the prototype air bearing base on the air bearing mounting plate – driven stage (D972119-1), and secure using ¼-28 x 1.75" bolts (12 places). Torque the bolts to 75 in-lbs. Place the air bearing mid-surface on the base. Use 30 psi air (dry with 1μm filtration) during this operation. Still maintaining the air supply, place the air bearing spherical surface on the mid-surface and increase air pressure to ~100 psi. Allow the air to flow for ~30 seconds to clear all foreign particles trapped between the bearing surfaces. Discontinue the air supply. This part of the assembly remained together throughout the alignment of all of the actuator sets.

Prepare the actuator set for installation on the air bearing mounting plate. The plastic dust bellows (4 total) on the actuators must be removed to gain access to the inside of the actuator from the top. The aluminum side panels that cover the optical LIMIT switches must be removed to gain side access to the limit switches. This is done by removing the remaining screws from the actuator side panels. Remove "ALL" wire ties that secure the internal wiring for the limit switches. Discard these ties. Loosen each of the optical LIMIT switches (HOME plus two LIMITs) but do not remove them from the actuator.

Mount the actuator set described in section 4.1 to the air bearing mounting plate to complete the U-V translation assembly. Alignment pins are provided to ensure proper clocking of the actuator set. Secure the actuator set to the mounting plate using four ¼x20 bolts. The bolted connections are made from the bottom side of the air bearing mounting plate. Torque the bolts to 65 in-lbs. The flexure jig (D972309-1) is used to complete the mechanical connection between the actuator set and the prototype air bearing. Be sure to provide 30 psi air (dry with 1 μm filtration) to the air bearing whenever working with the air bearing. Refer to drawing D972102 for illustration of the proper assembly. The flexure jig is used instead of the coarse U-V flexure to provide a nearly rigid mechanical link between the actuator sets and the air bearing. The coarse U-V flexure is too compliant and will introduce unknown displacements in the setup that cannot be accounted for in the calculations.

4.3 Position +U and +V LIMIT Switches

The process has been designed to minimize the complexity of the setup, but ensure sufficient travel and protection. The first step is to set the +U and +V LIMIT switches. *This setup procedure uses a local coordinate system that defines +U as a vector that points from the air bearing to the actuators. The V and W directions are defined using a right hand coordinate system.*

Provide 30 psi air (dry with 1 μm filtration) to the air bearing during the entire setup process. Begin by moving the actuator set so that the air bearing mid-surface gently rests equally on the two mechanical stops located nearest the -45° axis. The motors and NextSteps should remain off during these steps to allow the actuators to be freely positioned (by hand) without the use of the CAS electronics.

The air bearing mid-surface should apply a slight pressure against the mechanical stop bumpers (do not force). This can be identified by a slight change in color of the bumper (experience will help clarify this statement) as it separates from the dowel pin. The air bearing mid-surface should now be backed off ~1/32 (no more than 1/16”) from the rubber bumper. This will allow the LIMIT switches to react to motions that exceed prescribed limits before the mechanical stops do. The actuators are now properly positioned for maximum travel.

A power supply and one set of three LED’s are necessary to set the LIMIT switches accurately. The power supply is necessary to provide +5V (***warning: do not exceed 5V or the optical LIMIT switch will be permanently damaged***) to the LIMIT switches. The LED’s will let the user know when either the LIMIT switches or HOME switch has been tripped. Plug in a LIMIT switch cable and provide power to the LIMIT switches and LED’s. Move the +U LIMIT switch until the LED indicates that the LIMIT switch has been tripped. Secure the switch at this location using the screws provided. Repeat this process for the +V LIMIT switch and secure with the screws provided.

4.4 Position –U and –V Limit Switches

The –U and –V LIMIT switches are set using the same procedure described in section 4.3 to set the +U and +V LIMIT switches, with minor changes. The actuators set is to be moved so that the air bearing mid-surface gently rests equally on the two mechanical stops nearest the +135° axis. The procedure continues as described in section 4.3.

4.5 Position Home Switch

The two LIMIT switches described in sections 4.3 and 4.4 are spaced such that the HOME switch can not be set to define an exact home position using on one side of the dogear located below the actuator carriage. The HOME switch, however, will provide some coarse feedback (±1/8”) and may become useful for some circumstances. For this reason, the HOME switch is set by simply centering the HOME switch between the positive and negative LIMIT switches. The switch can be placed by eyeballing the center and secure it with the screws provided. All 18 actuator sets have been positioned in this manner.

4.6 Disassembly

Remove the flexure jig and the actuator set by reversing the procedure described in section 4.2. Discontinue supplying air to the air bearing once the flexure jig has been removed and the air bearing is protected from external forces. Leave the air bearing connected to the air bearing mounting plate if more than one actuator set requires LIMIT switch positioning.

The LIMIT and HOME switch wiring will need to be secured before closing up the side panels. Use small cable ties to secure the wiring from getting snagged, pulled or tangled in the actuator bearing set during operations. This is important to avoid a LIMIT or HOME switch failure and hours of debugging and rework.

Reinstall the U and V actuator side panels. Use only the screws that are accessible without disassembling either of the actuators or the spacer block. These panels are not structural, therefore, the one or two screws will be sufficient to secure the close-out panels. Reinstall the protective bellows. The actuator set is now ready to be installed and used at LIGO.