



A Johnson Electric Company

# **HR2**

# **Ultrasonic Motor**

# **User Manual**

D/N: MSP2458000-00 REV: C

August 29, 2012

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## Limited Warranty

Nanomotion (hereinafter NM) warrants the product (other than software) manufactured by it to be free from defects in material and workmanship for a period of time of one year (except those parts normally considered as consumable/expendable components such as motor conditioning brushes). The warranty commences thirty (30) days from the date of shipment.

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NM's sole and exclusive obligation under this warranty provision shall be to repair, or at its sole option exchange defective products or the relevant part or component, but only if : (i) the Purchaser reports the defect to NM in writing and provides a description of the defective product and complete information about the manner of its discovery within ten (10) days of its discovery; (ii) NM has the opportunity to investigate the reported defect and determines that the defect arises from faulty material, parts or workmanship; and (iii) the Purchaser returns the affected product to a location designated by NM. These provisions constitute the exclusive remedy of the Purchaser for product defects or any other claim of liability in connection with the purchase or use of NM products.

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The warranty stands only when the motors are used with the NM drivers/ amplifiers.

NM shall not in any event have obligations or liabilities to the Purchaser or any other party for loss of profits, loss of use or incidental, increased cost of operation or delays in operation, special or consequential damages, whether based on contract, tort (including negligence), strict liability, or any other theory or form of action, even if NM has been advised of the possibility thereof, arising out of or in connection with the manufacture, sale, delivery, use, repair or performance of the NM products. Without limiting the generality of the preceding sentence, NM shall not be liable to the Purchaser for personal injury or property damages.

## Patent Information

Nanomotion products are covered under one or more of the following registered or applied for patents.

5,453,653; 5,616,980; 5,714,833; 111597; 5,640,063; 6,247,338; 6,244,076; 6,747,391;  
6,661,153; 69838991.3; 6,384,515; 7,119,477; 7,075,211; 69932359.5; 1186063; 7,211,929;  
69941195.5; 1577961; 4813708; 6,879,085; 6,979,936; 7,439,652; 7061158 ;1800356;

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1800356; 1800356; 2007-533057 (pending); 2011-093431 (pending); 7,876,509; 10-2007-7009928 (pending); 200780019448.6 ; 7713361.9 (pending); 12/294,926 (pending); GB2008000004178 (pending); GB2009000003796 (pending); 12/398,216 (pending); GB2446428; 12/517,261 (pending); 08702695.1 (pending); 10-2009-7017629 (pending); 12/524,164 (pending); 12/581,194 (pending)

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## Revision History

ECO	Revision	Release date	Details
NA	NA	Aug. 2012	Administrative change – added patent information section in front matter.

## CE Compliance

The motors and drivers comply to the following directive:

Safety : IEC 61010-1:1990

EMC : 89/336/EEC as amended by 92/31/EEC and 93/68/EEC

Harmonized Standards to which conformity is declared:

EN 50081- 2:1993/EN 55011:1991

Generic Emission Standards Class A for radiated emission and Class B for conducted emission.

EN 50082- 2:1995 Generic Immunity Standard

**NOTE:** *UHV motors are designed for convenient interface to the UHV setup. The motors are therefore supplied with three open electrical leads. Whereas standard motors comply with CE regulations and the UHV motors have the same internal design as standard motors, the UHV motors are supplied as components and CE conformity in both EMI and Safety must be implemented as part of the UHV system design.*

## **Preface**

This Installation Manual is designed to help the reader install and operate the various types of Nanomotion's HR2 piezoceramic Motors. This manual assumes that the reader has a fundamental understanding of basic servo systems, as well as motion control concepts and applicable safety procedures.

The manual describes the physical dimensions as well as the mechanical and electrical installation procedures for these motors.

## **Warranty**

The motors are covered by warranty for a period of twelve months from the date of invoice.

The following voids the warranty:


Misuse or incorrect mounting, incorrect electrical connections, removal of motor cover or of serial number, modification of parts, and any other use that is not according to the cautions and warnings provided in this guide.

Liability for replacement will be determined after inspection of any defective item by Nanomotion or an approved agent.

## Definition of Terms

**NOTE:** *Additional useful information.*

**CAUTION:** *Identifies conditions or practices that could result in damage to this product or other property.*

 **WARNING:** *Identifies conditions or practices that could result in personal injury, damage to the product or damage to other property.*

## Warnings and Cautions

### **WARNINGS**

***Do not remove the cover of the motor or disassemble its connector. High voltage inside.***

***Be sure to ground the motor to the electrical network ground (according to the following instructions) before operating the motor.***

### **CAUTIONS**

- *Arrows on motor indicate direction of motion. Align accordingly.*
- *Do not set power-on unless motor is mounted and preloaded!*
- *Do not immerse the motor in any liquid or cleaning agent.*
- *Use only a clean cloth to wipe the motor.*
- *Be sure that the motor, and specifically the 'finger tips', are not subjected to mechanical shocks.*
- *Be sure that the distance of the motor to the plate enables the motor finger tip to contact the driving plate, otherwise the motor might be damaged during operation.*
- *The mounting base and the method used for mounting should be designed for maximum mechanical rigidity and stiffness.*
- *Reducing the length of the supplied motor cable may damage the motor. Do not attempt to shorten the cable without prior confirmation by Nanomotion.*
- *Extending the motor cable will not damage the motor, however it will affect its performance.*

## Table of Contents

<b>1. INTRODUCTION .....</b>	<b>9</b>
<b>1.1 About the Motor.....</b>	<b>9</b>
<b>1.2 Vacuum Motors .....</b>	<b>9</b>
<b>1.3 HR2 System Parts .....</b>	<b>10</b>
<b>1.4 Handling.....</b>	<b>10</b>
<b>1.5 Installation and Servicing .....</b>	<b>10</b>
<b>2. PREPARATION AND INSTALLATION .....</b>	<b>11</b>
<b>2.1 Preparation .....</b>	<b>11</b>
2.1.1 Mounting Base .....	12
2.1.2 Limiting Stage Motion .....	13
<b>2.2 Motor Installation .....</b>	<b>13</b>
2.2.1 Bonding the Driving Plate to the Stage .....	14
2.2.2 Mounting the Motor .....	17
2.2.3 Motor Grounding .....	19
2.2.4 Motor Connections .....	19
2.2.4.1 Motor Connector Pinout.....	20
2.2.4.2 System Electrical Configuration.....	21
2.2.5 Motor Run-In .....	21
<b>3. SPECIFICATIONS.....</b>	<b>22</b>
<b>3.1 General.....</b>	<b>22</b>
<b>3.2 Specification Parameters.....</b>	<b>24</b>
3.2.1 Performance.....	24
3.2.2 Electrical .....	24
3.2.3 Environmental .....	24
3.2.4 Physical Dimensions .....	24
<b>3.3 Thermal Envelope of Performance (EOP).....</b>	<b>25</b>
3.3.1 Description .....	25
3.3.2 Stage Heat Dissipation Consideration .....	26
3.3.3 Thermal EOP for HR2 Motor Driven by AB1A, AB2 AB4 Drivers .....	27
3.3.3.1 An Example for Defining the EOP for AB1A Driver in Vacuum Environment...	29
3.3.4 EOP for HR Motors Driven by AB5, AB51 Drivers .....	29
3.3.4.1 An Example for Defining the EOP for AB5 Driver in Vacuum Environment, Brake_On Mode.....	33
3.3.4.2 An Example for Defining the EOP for AB5 Driver in Vacuum Environment, Brake_Off Mode.....	33
<b>3.4 Schematics .....</b>	<b>34</b>
3.4.1 Dimensions for Standard and High-Vacuum Motors .....	34
3.4.2 Dimensions for Ultra-High-Vacuum Motors.....	35
3.4.3 Mounting Base Dimensions .....	36



# 1. Introduction

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## 1.1 About the Motor

The HR2 motors are high precision ceramic motors. Designed and manufactured by Nanomotion, Ltd., the HR2 motors combine unlimited stroke with high resolution in compact dimensions. Among its applications are microscopy, precision motion, robotics, etc.

The motors provide a linear response to the input voltage. The operation of the motor and driver resembles that of a DC-motor driven by a voltage amplifier.

The specifications described in this chapter apply only to the motor driven by AB1A Driver. Minor differences may result if AB2, AB4 or AB5 are used.

## 1.2 Vacuum Motors

Applications of the Nanomotion motors for vacuum and high-vacuum environments include wafer inspection metrology, scanning stages and lithography. The HR2-V and HR2-U motors are constructed of materials that have been selected and designed for high vacuum compatibility.

## 1.3 HR2 System Parts

A complete set for a single axis will comprise of the following:

- a) HR2 Motor
- b) 1.8mm spacer
- c) Ceramic Driving Plate for linear applications or Ceramic Driving Ring/Disk for rotary applications. (see section 2.2.1)
- d) One of the following drivers:
  - AB1A
  - AB2
  - AB4
  - AB5
  - XCD HR2

**NOTE:** For the first 4 driver options, use a standard off-the-shelf DC Controller with a servo rate of 10KHz or higher. You may consult Nanomotion for the recommended controller. The option for NCD Driver Controller Box consists of a driver and an integrated controller.

## 1.4 Handling

### **CAUTIONS**

*Do not set power-on unless the motor is mounted and preloaded!*

*Do not immerse the motor in any liquid or cleaning agent.*

*Use only a clean cloth to wipe the motor.*

*Be sure that the motor, and specifically the 'finger tips', are not subjected to mechanical shocks.*

## 1.5 Installation and Servicing

It is recommended to follow the installation instructions in this guide, when mounting and installing the motor. The HR2 does not contain any user-serviceable parts.

## 2. Preparation and Installation

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### 2.1 Preparation

For optimal motor performance, it is recommended to use the Ceramic driving plates provided by Nanomotion. These driving plates have been specifically designed to work with Nanomotion motors.

Substituting this plate with any other material might reduce motor performance or damage the motor.

**NOTE:** The instructions given in this section refer to the standard ceramic driving plates provided by Nanomotion. Nanomotion can not guarantee performance attained by plates purchased from other sources.

## 2.1.1 Mounting Base

Prepare a base with four *oval* holes as described in Section 3.2.8 - Mounting Base Dimensions. The base should be positioned perpendicular to the Ceramic driving plate that is bonded to the stage.

If necessary, refer to the schematic for motor dimensions.

**CAUTION:** *The mounting base and the method used for mounting should be designed for maximum mechanical rigidity and stiffness.*

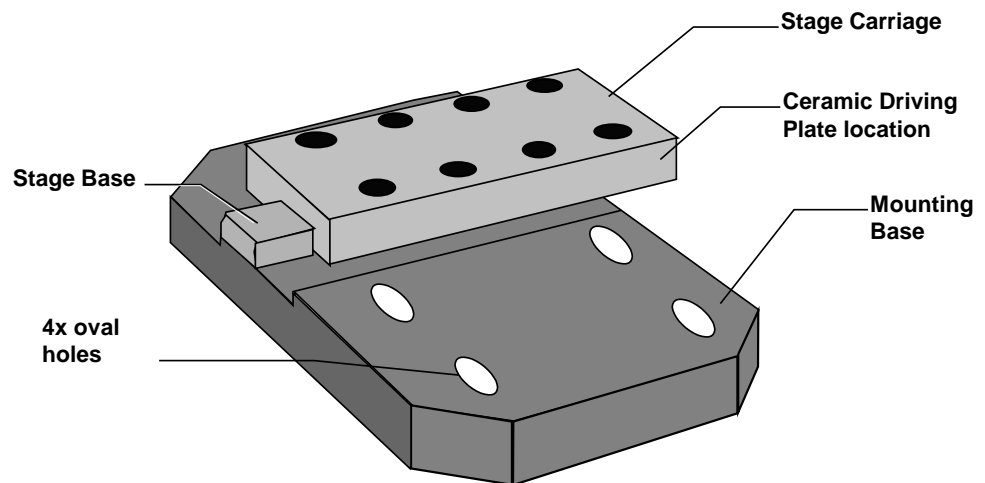


Figure 1: *Motor Mounting Base*

The mounting base dimensions diagram refers to the *front* surface of the Ceramic driving plate.

For driving plate dimensions please refer to the price list.

The four screws securing the motor to the mounting surface will be inserted from its underside. Any protrusion of the screws *might* interfere with motion on another axis.

### **2.1.2 Limiting Stage Motion**

The provided ceramic driving plate should not exceed the stage. It must be supported by a solid even backing along all its length, in order to avoid breaking when motor is pressed against it.

The Ceramic driving plate should also be at least 10 mm longer than the stage travel length, otherwise the motor finger tips might be damaged.

If the above requirements are not met, limit the stage travel distance using end stops.

## **2.2 Motor Installation**

The installation procedure consists of the following:

- Bonding the Ceramic Driving plate to the stage
- Mounting the motor
- Grounding the motor
- Connecting the motor to its driver

## 2.2.1 Bonding the Driving Plate to the Stage

The Driving Ceramic Plate interfaces between the motor 'finger tips' and the stage, and provides the required friction.

Bond the driving plate provided by Nanomotion to the stage surface interfacing with the motor 'finger tips', according to the instructions given in this section.

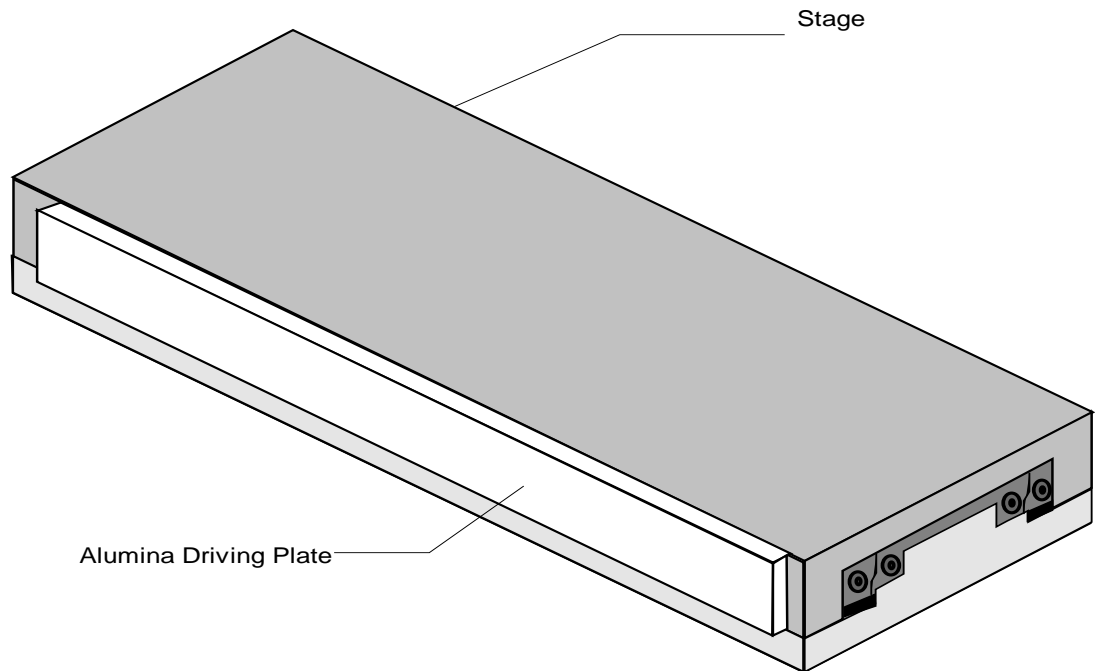
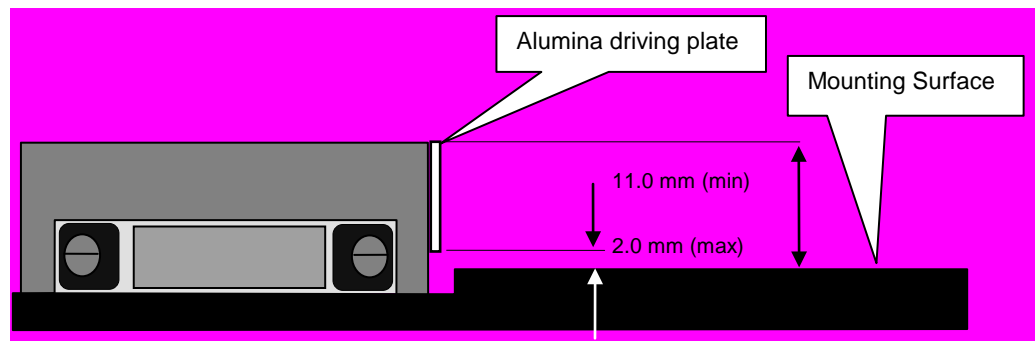


Figure 2: *Bonding the Ceramic Driving Plate*

1. Clean the bonding region on the stage, using a suitable agent such as Acetone or Methanol.
2. Peel off the self-adhesive backing paper on the Ceramic driving plate. The self adhesive tape is compatible with high-vacuum applications.
3. Referring to the figure below, place the plate in position, verifying that:
  - There is a maximum of 2.0mm between the lower edge of the Ceramic driving plate and the motor mounting surface.
  - There is a minimum of 11.0mm between the upper edge of the Ceramic driving plate and the motor mounting surface.



*Figure 3: Ceramic Driving Plate Position*

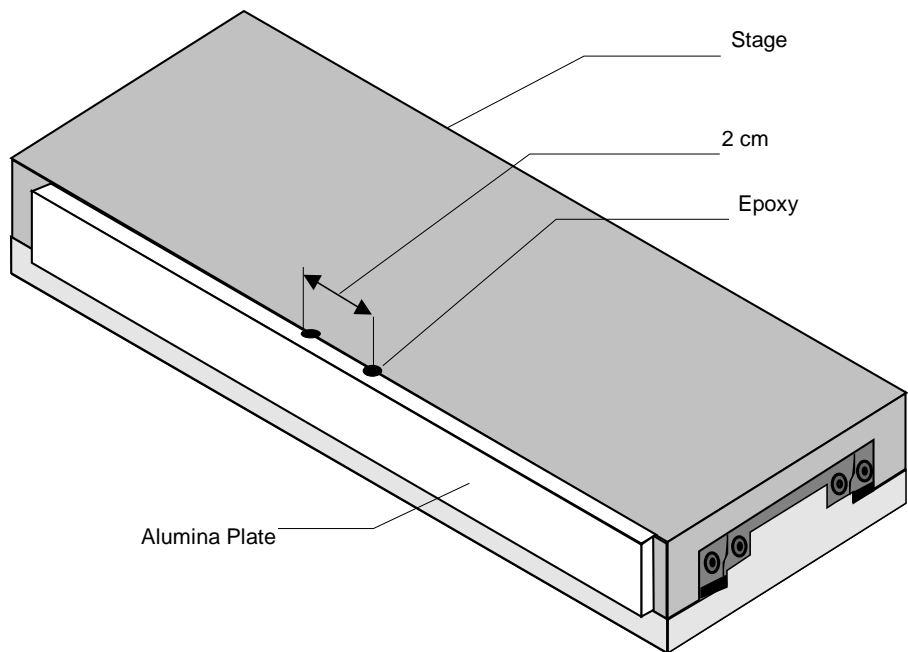
*Continued on the following page....*

- Referring to the figure below, apply two drops of epoxy adhesive, on the center of the Ceramic driving plate *upper* surface, about 2cm apart. The Epoxy must bond between the plate and the stage.

Recommended adhesive:

- Emerson & Cuming ecobond 24, for vacuum applications
- 3M 2216 epoxy or CIBA GEIGY Arldite Radite, for non-vacuum applications

**NOTE:** Be sure the epoxy contacts the upper surfaces of the plate and the stage carriage but does not flow over the Ceramic plate front surface.



*Figure 4: Securing the Ceramic Driving Plate to the Stage*

- Allow the required time period for curing, according to the Epoxy manufacturer specifications.
- Mount the motor according to the following section.



## 2.2.2 Mounting the Motor

After bonding the Ceramic driving plate to the stage, loosely mount the motor so it faces the Ceramic driving plate according to the instructions in this section.

**NOTE:** *The motor does not have an 'up' or 'down' side and may be mounted on either surface so that the cable protrudes from either the left or the right side.*

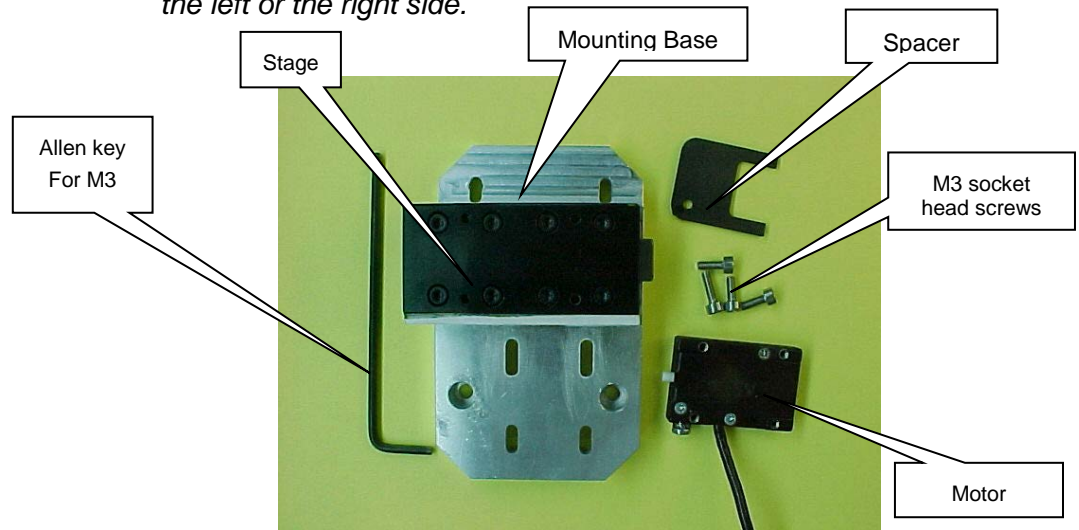
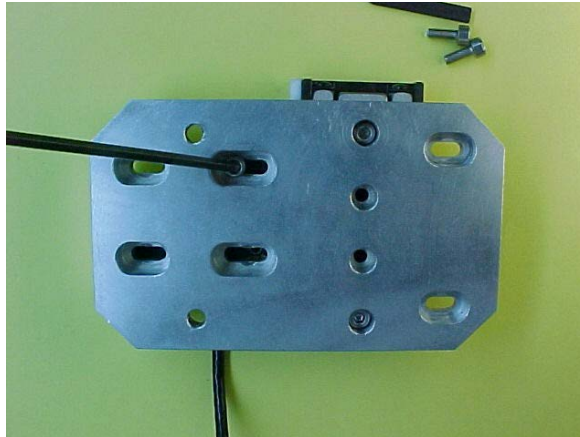


Figure 5: Accessories for mounting

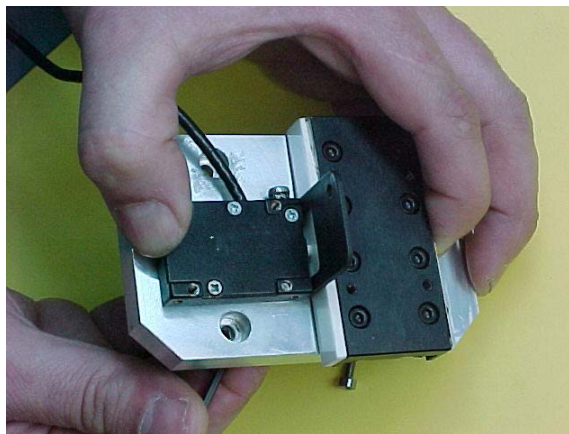
1. Align the motor to the four holes on the motor mounting surface.
2. Secure the motor to the surface using four M3 screws and spring washers inserted from the underside of the mounting surface. **Do not tighten yet.**
3. Adjust the distance between the motor and the Ceramic driving plate as follows:
  - Place the 1.8 mm spacer between the motor surface that *faces* the Ceramic driving plate, and the Ceramic driving plate.
  - Gently press the motor against the Ceramic plate to the thickness of the spacer.
  - *Lightly* screw the four motor screws and then *remove the spacer*.
    - *Fully* tighten the motor screws at a torque of 0.5 to 0.7Nm.
4. Ground the motor according to the following section.

Insert M3  
screws. Do not  
tighten yet



*Figure 6: Inseting screws*

Insert spacer between motor and  
ceramic drive strip.  
Press the motor against the spacer  
and tighten the screws.  
Pull spacer out.



*Figure 7: Spacing and tightening*

### 2.2.3 Motor Grounding

**Warning !!!**

***Be sure to ground the motor to the electrical network ground (according to the following instructions) before operating the motor.***

1. Prepare a grounding wire and a terminal connection with the following specifications:
  - Terminal diameter - for an M3 screw
  - Wire diameter - minimum 18 AWG
  - Wire length - maximum of 2 meter
2. Open the motor ground screw (figures 15 & 16) and connect the ground connection prepared in step-1.
3. Secure the terminal between the two lock washers.
4. Connect the other end of this cable to the electrical network ground.
5. Connect the motor to its driver according to the instructions given in the following section.

### 2.2.4 Motor Connections

This section describes the motor connector pinout and the connections to each of the available drivers.

Make sure the driver is set to operate with the HR2 motor series.

**CAUTIONS:**

*Reducing the length of the supplied motor cable may damage the motor. Do not attempt to shorten the cable without prior confirmation by Nanomotion.*

*Extending the motor cable will not damage the motor, however it will affect its performance.*

### 2.2.4.1 Motor Connector Pinout

**⚠ WARNING:** Do not remove the cover of the motor or disassemble its connector. High voltage inside.

**CAUTION:** Do not set power-on unless the motor is mounted and preloaded.

The motor driver connection is a standard 9 contacts D-type female connector whose pinout is given below.

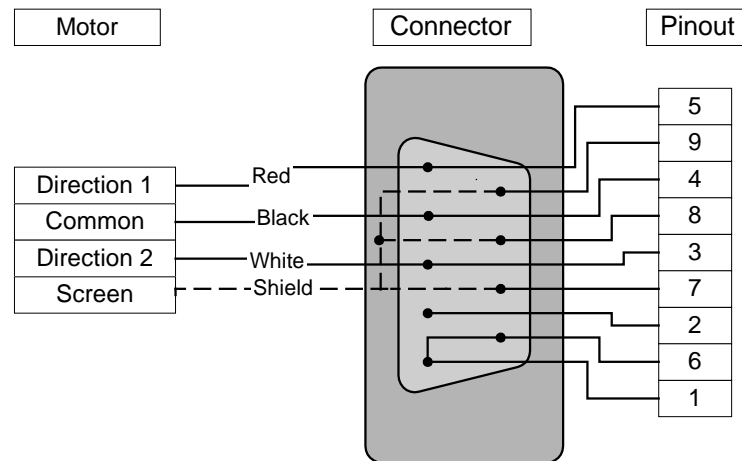


Figure 8: Motor Connector

**NOTE:** Pins 6 and 1 on the motor connector are shorted. This is done for safety reasons – driver voltage is disabled unless pins 1 & 6 are shorted when motor is connected.

#### For Ultra High Vacuum motor:

The HR2 –2-U motor does not have an outlet cable or a connector. Instead, there are 3 TFE jacketed wires extending outside the motor: 1 black wire, 1 red and 1 white wire. The red and white wires are directions 1 and 2 respectively, and the black wire is the common. Also, the safety shorting between pins 1 and 6 is not implemented and should be preformed by the user.

**⚠ WARNING**  
 Since there is no cable shielding the HR2-2-U motor case to the ground, it must be grounded by means of connection to the network ground. Please refer to section 2.2.3 in the manual for detailed instructions.

### 2.2.4.2 System Electrical Configuration

The Motor is to be operated by one of Nanomotion's drivers. Following is the two possible configurations:

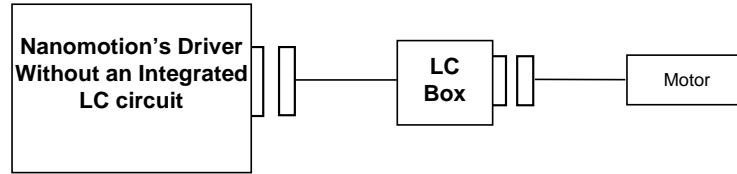


Figure 9: Connection to a driver using an external LC box

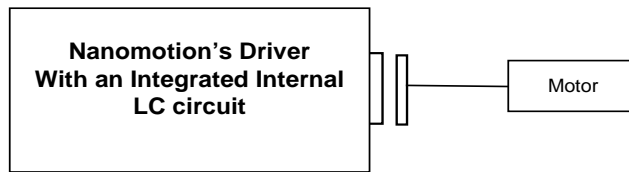


Figure 10: Connection to a Driver with internal LC circuit

### 2.2.5 Motor Run-In

Run-in of the motor is important to reduce wear rate of the system and to increase its lifetime.

The required run-in conditions are as follows:

- velocity - 100 mm/sec.
- Duty cycle - 50%.
- Duration - 4 hours.

When the run-in is completed, carefully clean the ceramic strip with a Q-Tip soaked with IPA, **without dismounting the motor.**

**General remarks:**

1. The procedure should be repeated if the motor is disconnected and then reinstalled.
2. **Do not perform run-in in a vacuum environment.**

## 3. Specifications

### 3.1 General

These specifications apply to the standard motor driven by the AB1A Driver Box. The motor features a linear voltage response. The motor and driver can be modeled as a DC-motor with friction driven by a voltage amplifier, as illustrated in the following diagram.

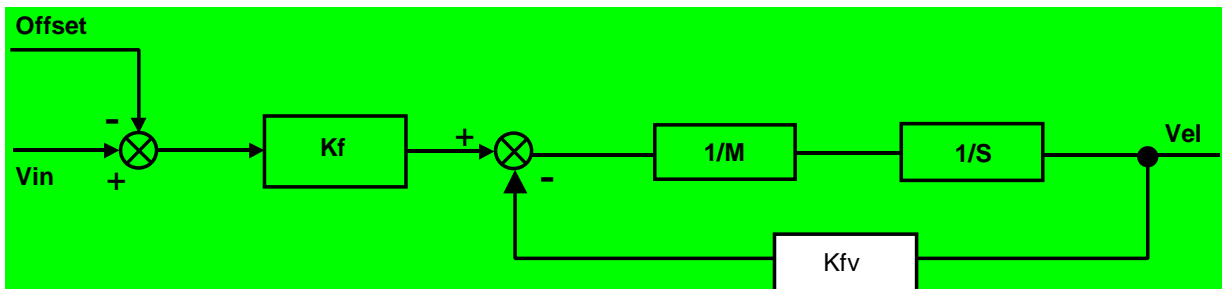


Figure 11: *Block Diagram of the Motor and Driver*

Where:

- $V_{in}$  - Command to the driver -10 to +10 [V]
- $K_f$  - Force constant [ N/V ]
- $Offset$  - Starting voltage [ V ]
- $K_{fv}$  - Velocity damping factor (similar to back EMF) [ N x sec / m ]
- $Vel$  - Motor velocity [ m/Sec ]
- $M$  - Moving mass [ kg ]
- $S$  - Laplace variable [ 1/sec ]

A block diagram of a typical HR2 Driver/Motor Sub-system is shown below.

A command voltage of  $\pm 10\text{V}$  is applied to the driver. The driver then generates a 39.6Khz sine wave (V motor) whose amplitude is a function of command voltage. The sine wave drives the HR2 motor.

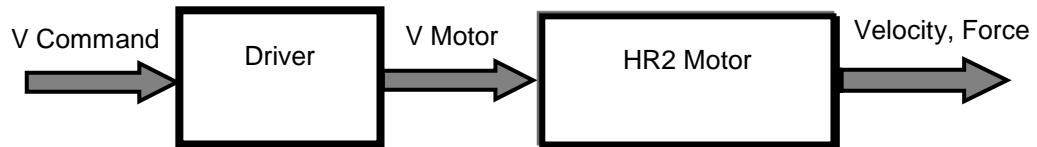


Figure 12: *Block Diagram of a typical HR2 Driver/Motor Sub-system*

## 3.2 Specification Parameters

### 3.2.1 Performance

Maximum Allowable Velocity:	250 [mm/sec]
Dynamic Stall Force:	7 to 9 [N]
Static Holding Force	7 [N] (reference value)
Non-Energized Stiffness	1.4 to 1.8 [N/ $\mu$ m]
Nominal Preload on Stage	36 [N]
Kf	1 to 2 [N/Volt command] – driver & command dependant
Kfv	24 to 36 [N • sec/m]
Offset	1 to 2 [V] – Driver dependant
Attainable Resolution	Better than 100 nm – see application notes.
Nominal Lifetime	20,000 hours under nominal operating conditions

### 3.2.2 Electrical

Maximal Voltage:	280Vrms, 39.6KHz, sine wave
Maximal Current consumption :	250 mA rms
Maximal Power Consumption :	10W

### 3.2.3 Environmental

Ambient Temperature:	0 - 50°C
Storage:	-40°C - +70°C
Humidity:	0 - 80% non condensing
Vacuum level (high-vacuum motors):	$10^{-7}$ Torr (guaranteed only after baking)
Vacuum level (ultra-high-vacuum motors):	$10^{-10}$ Torr (guaranteed only after baking)
Maximum Baking Temperature (for vacuum motors):	120°C (140°C for ultra high vacuum motor)

### 3.2.4 Physical Dimensions

Length:	40.5mm
Width:	25.7mm
Height:	12.7mm
Weight:	40/60gr. (high & ultra high vacuum motors /standard motor).



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## 3.3 Thermal Envelope of Performance (EOP)

### 3.3.1 Description

Motor operating temperature is a result of the balance between heat generation and heat dissipation.

- The heat generation depends on motor's work regime (driver command level).
- The heat is dissipated through the following heat transfer mechanisms: conduction, radiation and convection (the convection mechanism is negligible in vacuum environment).

The heat dissipation mechanisms should be able to dissipate the heat generated in order to avoid overheating. The EOP gives the user the tools to assess the permitted operating conditions (for set ambient temperature and command, deriving the duty cycle and maximal continuous operation that assures safe operation).

The user can either operate the motor for an extended period of time at a specific duty cycle or alternatively, can operate the motor for a continuous time period specified under “Maximal Continuous Operation Time” (see graphs and tables in sections 3.3.3 and 3.3.4). After the continuous operation is completed, the driver must be disabled to cool down the motor for 400 sec in air and for 700 sec in vacuum environment.

**Notes:**

- *The duty cycle is the ratio of the operation time and the total work cycle (operation time + idle time).*
- *When operating the motor with the AB5/AB51 driver continuously in Brake\_Off Mode (refer to section 3.3.4 "EOP for HR Motors Driven by AB5, AB51 Driver"), the motor consumes power at all times, even when the control command voltage is "0" (zero) thus the time at "0" command is accounted in the heating process and reduces the thermal EOP.*
- *Upon operating a motion system in vacuum, it is expected that the Coefficient of Friction of the bearing structure will increase. This may require changing the system operation point on the thermal EOP curves.*

### **3.3.2 Stage Heat Dissipation Consideration**

The motor heat dissipation mechanism is by convection and radiation to the motor case, and by conduction through motor's 'finger tips'.

Hence, the motor and the Ceramic Driving Strip bases, must both be thermally designed to dissipate 2W each (per motor's 'finger tip'), with maximum temperature rise of 15°C.

### 3.3.3 Thermal EOP for HR2 Motor Driven by AB1A, AB2 AB4 Drivers

Figure 1 illustrates motor velocity as a function of the applied driver command voltage. Allowing up to 30 mm/sec variations, use it as a reference and as a guideline for expected motor performance:

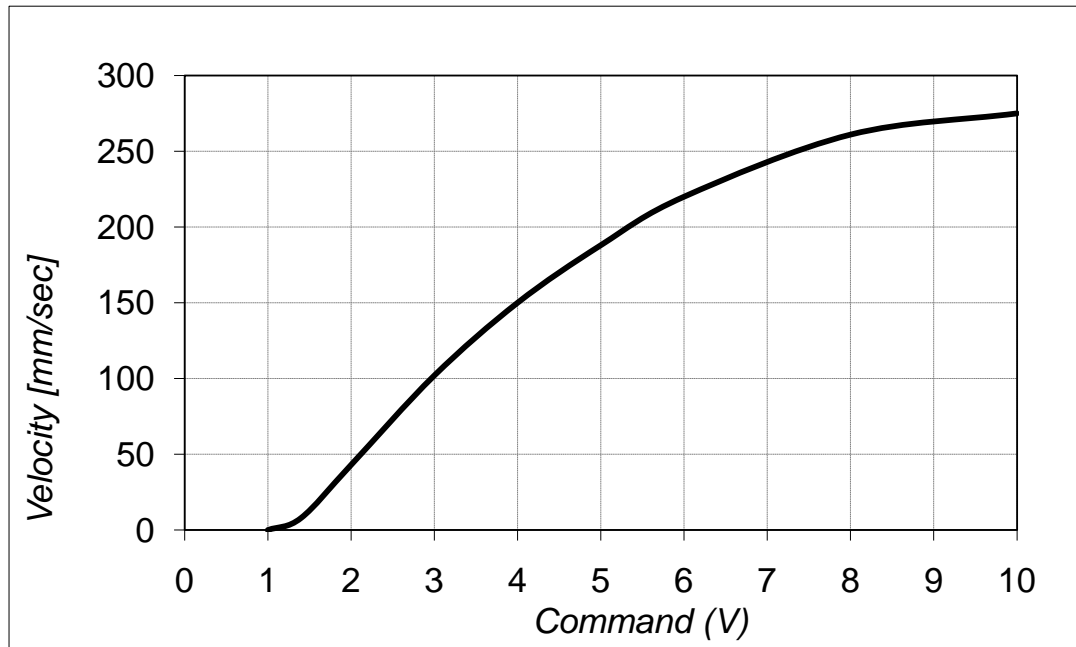


Figure 1: Motor Velocity vs. Command<sup>1</sup>

Figure 2 and Table 1 are designed to help the user determining the correct envelope of performance and avoid overheating and damaging the motor.

<sup>1</sup> The motor operates horizontally at room temperature and low duty cycle (< 10%). It interfaces with the Ceramic Driving Strip (according to Nanomotion Specifications) and a cross-roller high quality slide.

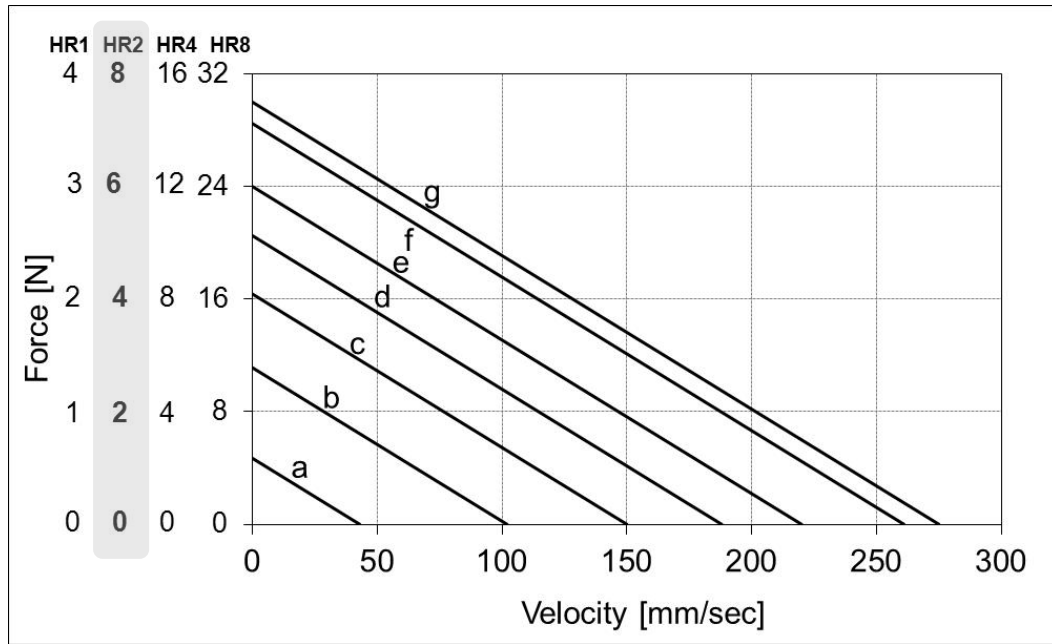


Figure 2: Motor Force vs. Velocity at the Various Work Regimes (a-g)

AB1A, AB2, AB4						
Curve	Air 25°C		Air 50°C		Vacuum	
	Duty Cycle [%]	Maximal Continuous Operation time [sec]	Duty Cycle [%]	Maximal Continuous Operation time [sec]	Duty Cycle [%]	Maximal Continuous Operation time [sec]
<b>a</b>	100	∞	100	∞	100	∞
<b>b</b>	100	∞	100	∞	44	184
<b>c</b>	100	∞	92	137	26	107
<b>d</b>	100	∞	62	93	17	72
<b>e</b>	78	87	47	70	13	55
<b>f</b>	56	62	33	50	9	39
<b>g</b>	50	56	30	45	8	35

Table 1: EOP Table for HR Motors Driven by AB1A, AB2, AB4

### **3.3.3.1 An Example for Defining the EOP for AB1A Driver in Vacuum Environment**

An example for using the graph and table (Figure 2 and Table 1) for the AB1A driver:

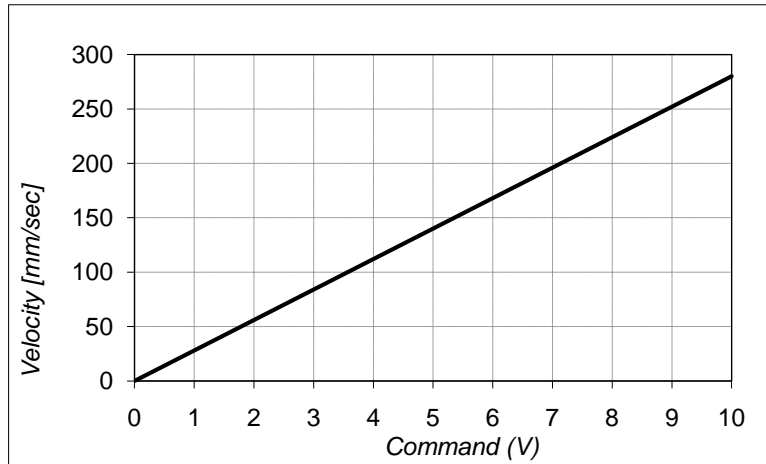
A vacuum application requires approximately 2.5N at a velocity of 100mm/sec. The graph shows that this point of operation corresponds to the curve “d”.

The table shows that curve “d” and a vacuum environment require that a duty cycle of 17% will not be exceeded and the maximum continuous operation time is limited to 72 seconds.

### **3.3.4 EOP for HR Motors Driven by AB5, AB51 Drivers**

The AB5, AB51 drivers are preferable for a perfect servo tracking and/or very low ripple constant velocity. Refer to the "AB5 and AB51 Drivers User Manual", D/N: AB05458200. The AB5 unique features result in the motor consuming more power and in a lower EOP, compared to the EOP for a motor operating with the AB1A driver. The AB51 driver is a modified version of the AB5 driver, which gives a higher EOP, compared to the AB5 driver, with some adverse effect on control performance in respect to tracking error and low velocity ripple.

Figure 3 illustrates motor velocity as a function of the applied AB5/AB51 driver command voltage. Allowing up to 30 mm/sec variations, use it as a reference and as a guideline for expected motor performance:



*Figure 3: Velocity vs. Command Using the AB5/AB51 Driver*

Figure 4 and Table 2 are designed to help the user determining the correct envelope of performance and avoid overheating and damaging the motor.

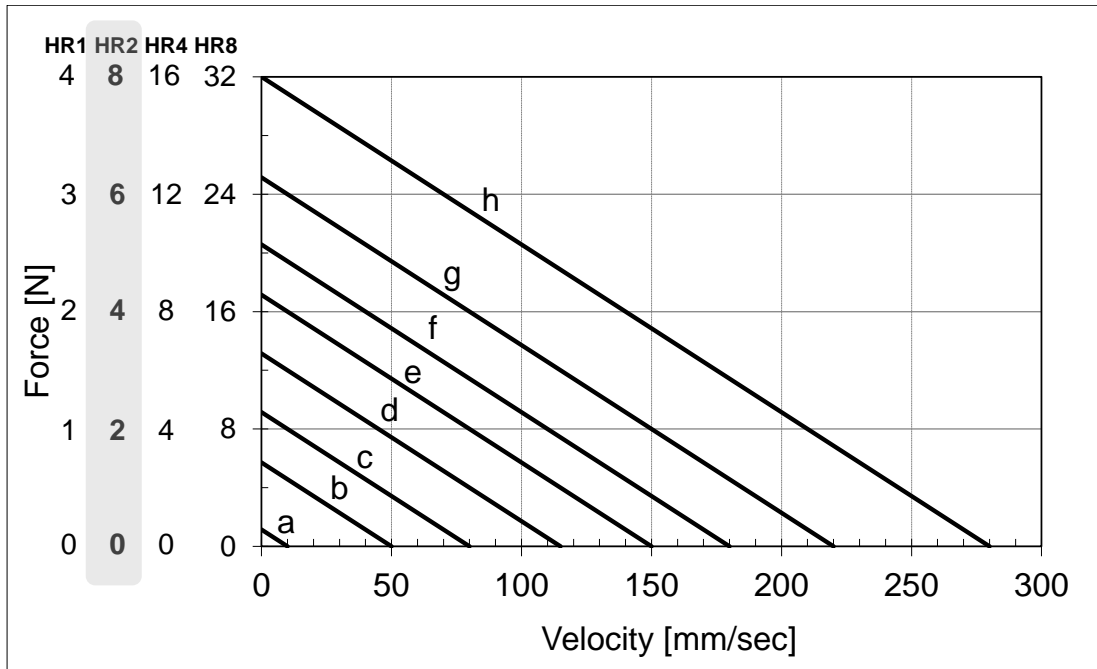


Figure 4: Force vs. Velocity Using the AB5/AB51 Driver at the Various Work Regimes (a-h)

AB5					
Curve	Air 25°C			Vacuum	
	Duty Cycle Brake_Off [%]	Duty Cycle Brake_On [%]	Maximal Continuous Operation time [sec]	Duty Cycle Brake_On [%]	Maximal Continuous Operation time [sec]
“0”÷a	100	100	∞	28	230
b	100	100	∞	23	210
c	100	100	∞	19	150
d	100	100	∞	14	110
e	50	80	280	13	90
f	33	58	170	12	66
g	24	45	77	10	44
h	11	28	32	6.5	25

Table 2: EOP Table for HR Motors Driven by AB5 (Standard LUT)

AB51					
Curve	Air 25°C			Vacuum	
	Duty Cycle Brake_Off [%]	Duty Cycle Brake_On [%]	Maximal Continuous Operation time [sec]	Duty Cycle Brake_On [%]	Maximal Continuous Operation time [sec]
"0"÷a	100	100	∞	56	500
b	100	100	∞	54	450
c	100	100	∞	45	280
d	100	100	∞	33	170
e	100	100	∞	23	100
f	53	58	170	16	66
g	33	48	77	10	44
h	17	28	32	6.5	25

Table 3: EOP Table for HR Motors Driven by the AB51 Driver (Reduced LUT).



**Note:**

- In the Brake\_Off Mode the full advantage of the AB5 driver is enabled giving a linear response, best tracking and low velocity performance. Using this mode, the motor operates continuously, even at "0" command and special attention must be given to maintain the work regime within the permitted "Duty Cycle" and "Maximal Continuous Operation Time" (refer to Table 2 and Table 3). Once the operation time has reached the "Maximal Continuous Operation Time", even at Brake\_Off Mode without motion (!) the driver must be disabled to allow the motor to cool down for at least 400 seconds in air and 700 sec in vacuum environment.



### 3.3.4.1 An Example for Defining the EOP for AB5 Driver in Vacuum Environment, Brake\_On Mode

A vacuum application requires 2N at a velocity of 80mm/sec and the motor is disabled when stand still (Brake\_On Mode). The graph (see Figure 4) shows that this point of operation corresponds to the curve "e" (see Table 2).

Table 2 for AB5 in Brake\_On Mode shows that curve "e" and a vacuum environment require that a duty cycle of 13% will not be exceeded and the maximum continuous operation time is limited to 90 seconds. Alternatively AB51 can be used giving duty cycle and continuous operation of 23% and 100 sec respectively.

The same conditions under Air at 25°C will result in 100% Duty Cycle and unlimited continuous operation.

### 3.3.4.2 An Example for Defining the EOP for AB5 Driver in Vacuum Environment, Brake\_Off Mode

When Brake\_Off Mode is used under vacuum conditions the motor will overheat at any duty cycle, if operated for a prolong time. To calculate the max operation time, use curve "0÷a" (see Table 2) for time at "0" command and the operation curve for the operating time according to the following formula:

$$T_{max} = (\text{max continues operation at the operation regime}) * DC + (\text{max continuous operation under regime "a"}) * (1-DC).$$

If operating under curve "c" (see Table 2), using AB5 in a duty cycle of 10%, the total operation time is:

$$T_{max} = 150 * 0.1 + 230 * (1-0.9) = 222 \text{ sec}$$

Once Tmax is reached, the driver should be disabled for a period of 700 sec.

### 3.4 Schematics

#### 3.4.1 Dimensions for Standard and High-Vacuum Motors

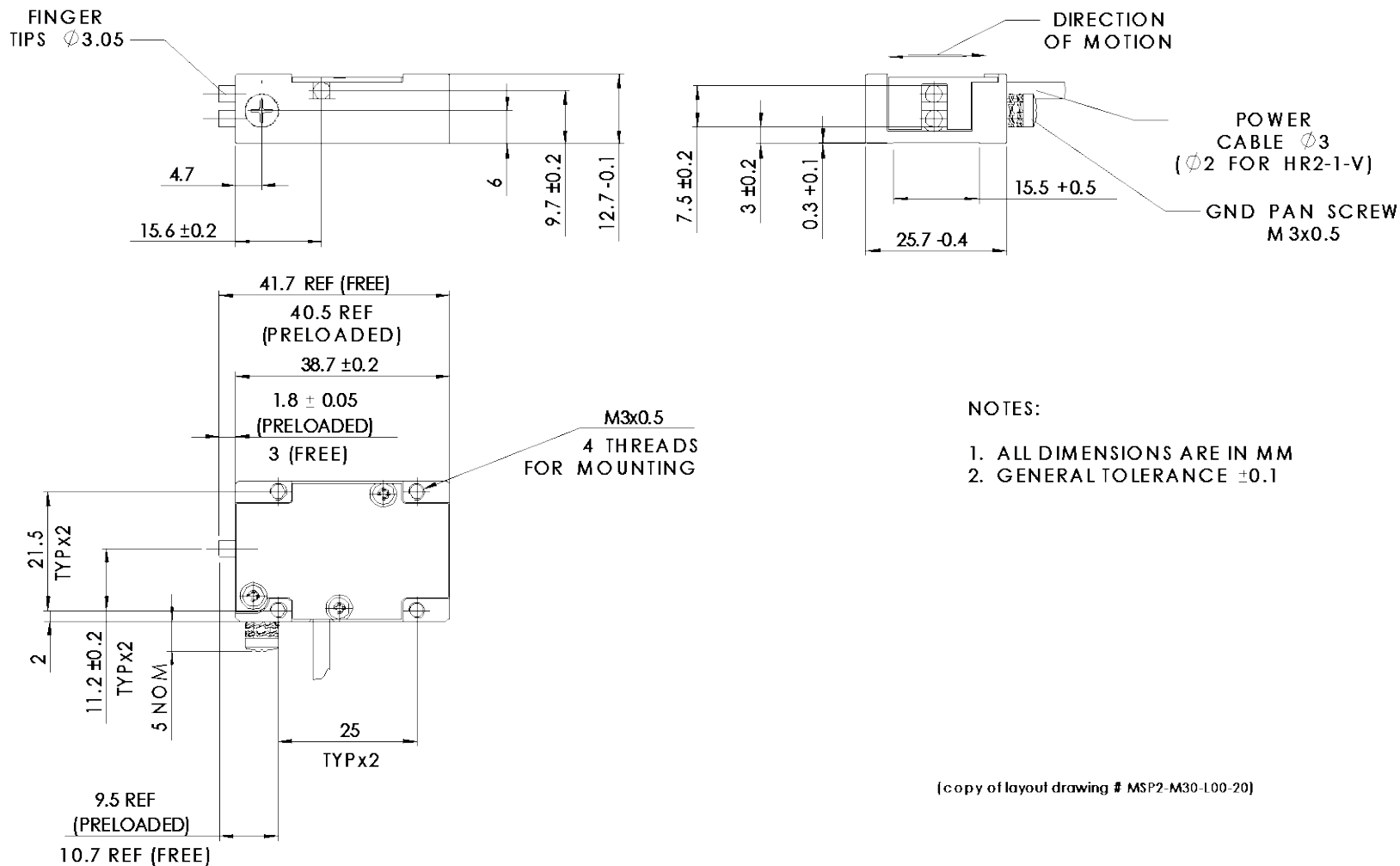


Figure 13: Dimensions for Standard and High-Vacuum Motors

### 3.4.2 Dimensions for Ultra-High-Vacuum Motors

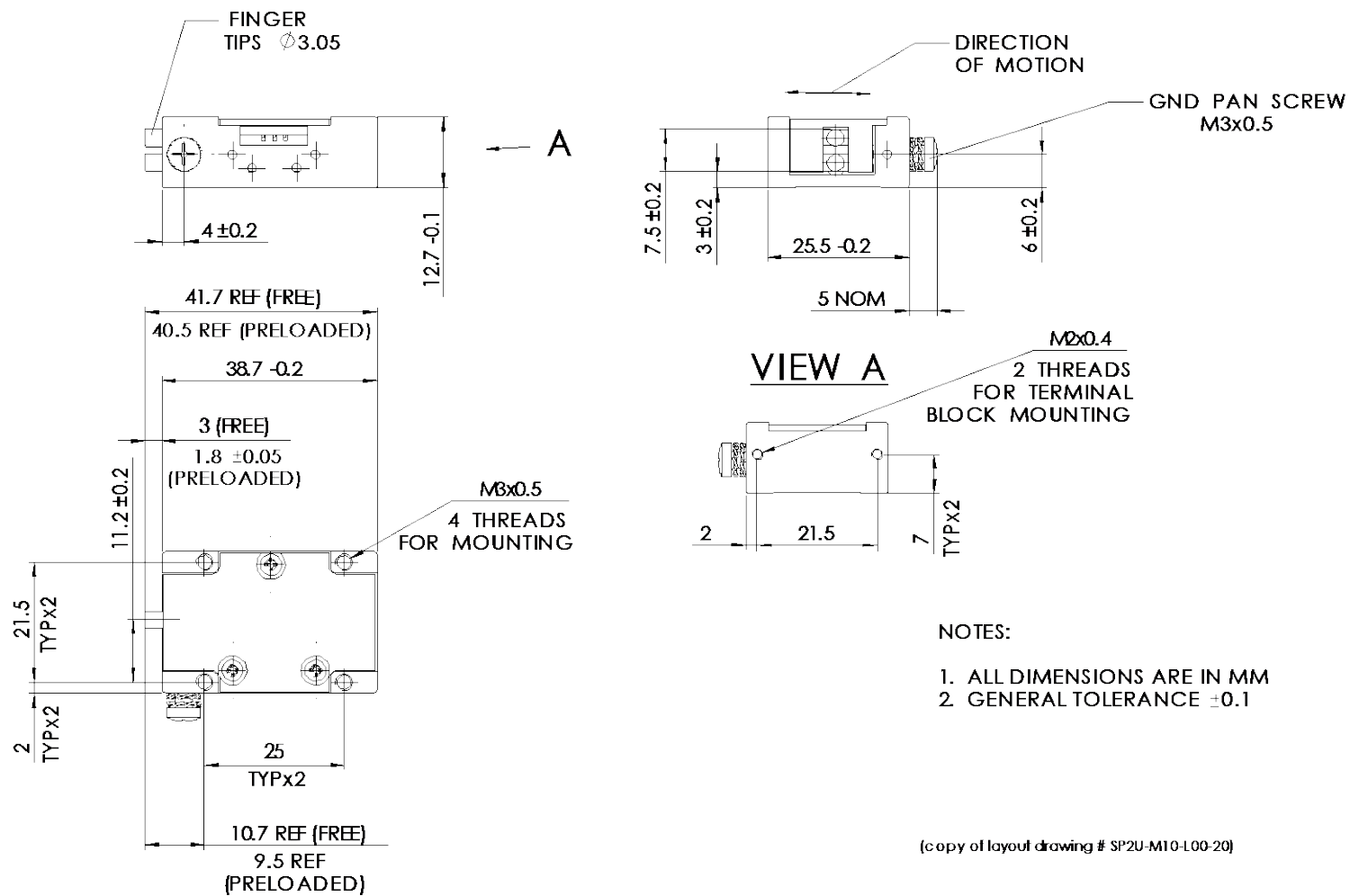


Figure 14: Dimensions for Ultra-High-Vacuum Motors

### 3.4.3 Mounting Base Dimensions

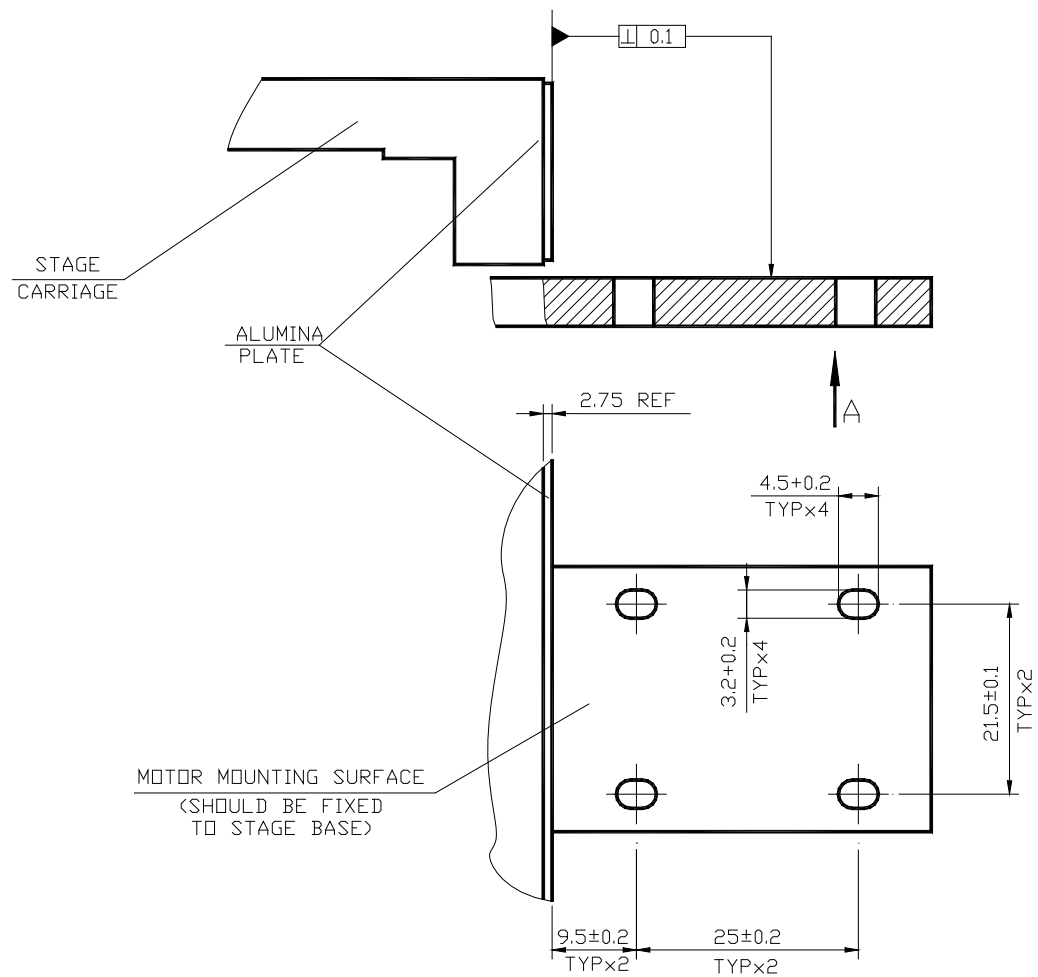


Figure 15: *Base Layout*