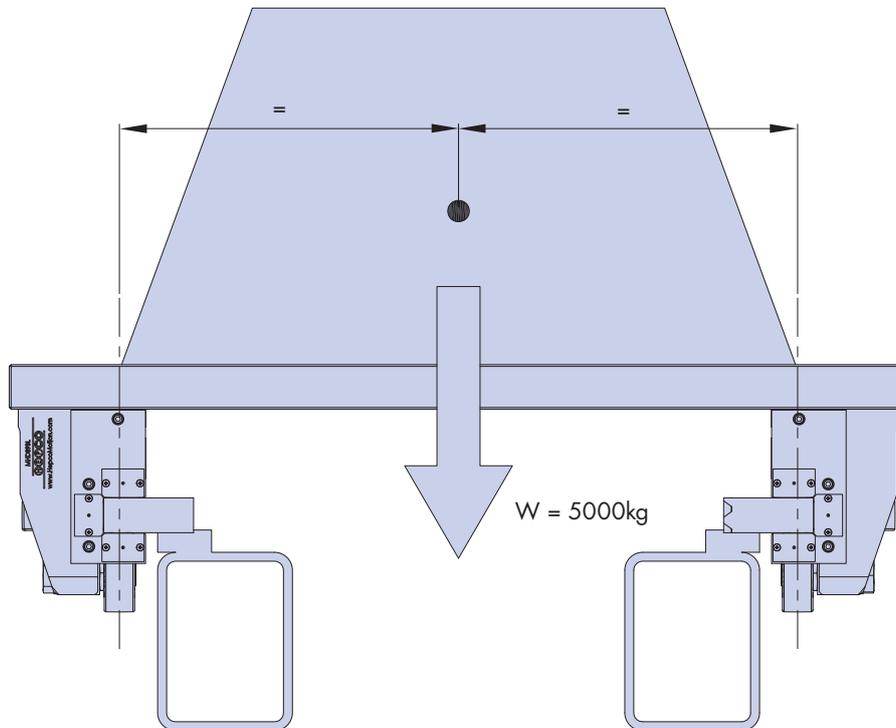


## MHD Load/Life Calculations

### Example 1



A system with a combined mass of 5000kg is centrally positioned on a carriage fitted with four bearing blocks. Lubrication is assured by the fitting of optional lubrication blocks. The stroke length for the system is 5m and the system runs at 0.5m/s on a 50% duty cycle for 40 hours per week. Inertial moments acting on the system during acceleration are ignored for the purposes of this calculation. The only loading for the slide system is the combined weight of the carriage and the supported mass.

The total weight carried by the four bearings is calculated to be 49,050N (= mass x g = 5000kg x 9.81m/s<sup>2</sup> = 49,050N). Since this weight is evenly distributed between the four bearing blocks, each block carries 25% of the load, namely 12,262.5N.

In this example the load is simply acting downwards, it is the upper twin row taper roller bearings which therefore carry the load. The life for these bearings is given by the equation (refer to the MHD catalogue, P.6):

$$\text{Upper bearing life (km)} = 1000 \times \left( \frac{L_{1A(\max)}}{L_{1A}} \right)^{3.3}$$

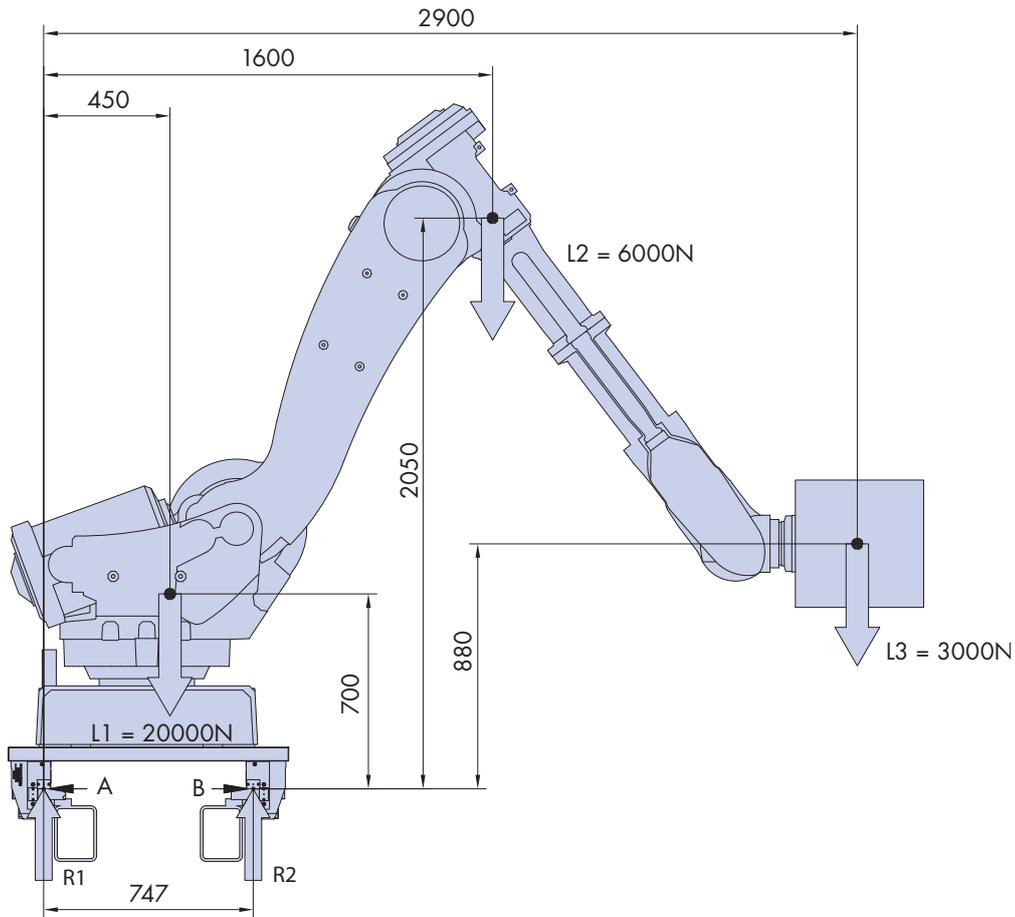
Where  $L_{1A(\max)} = 34,000\text{N}$  and  $L_{1A} = 12,262.5\text{N}$

The upper bearing life is therefore calculated to be approximately 28,945km.

With the above duty, the system travels 0.5m/s x 60 x 60 x 40 (seconds/week) x 0.5 (50% duty cycle) = 36,000m or 36km per week. The anticipated system life is therefore 28,945km/36 = 804 weeks or about 15.5 years.

# MHD Load/Life Calculations

## Example 2



An MHD system is utilised in a robot application where a robot is mounted on a rack-driven carriage that enables it to traverse along a linear axis for a pick and place operation. The diagram shows how the robot is positioned during its working cycle. The outstretched robot arm has three centres of mass whose positions and values are indicated in Example 2, shown above. The centres of mass all lie on the same plane which is central relative to the length of the carriage. The working cycle requires the robot to move between two workstations 10m apart. The system runs at 1m/s on a 40% duty cycle for 40 hours per week. The inertial moment on start up and slow down is ignored for the purposes of this calculation, since the acceleration is considered to be very small.

The offset weight has the effect of loading up the top bearings on the right hand side of the carriage and reducing the load on the top bearings on the left hand side of the carriage. The loads carried by the bearings are calculated as follows:

[summing all forces]	$R1 + R2 = L = 29000N$
[taking moments about A]	$R2 \times 0.747m - (0.45m \times 20000N) - (1.6m \times 6000N) - (2.9m \times 3000N) = 0$
[re-arranging above]	$R2 = 27300 / 0.747 = 36546N$
[substituting in first equation]	$R1 + 36546 = 29000N \therefore R1 = -7546N$

It can be seen from the above equations that the blocks on the right hand side of the track are heavily loaded and that it is the top bearings that carry this load. Whereas the blocks on the left-hand side are much less heavily loaded and it is the lower bearings that carry the load and which resist the turning moment from the load. It is therefore the top bearings that will dictate the life of the system.

Both R1 and R2 are supported by two bearing blocks, so each block experiences half the load. The most heavily loaded block therefore experiences a load of  $36546/2 = 18273N$ .

Using the equation for life for the top bearing the life in km is found to be:

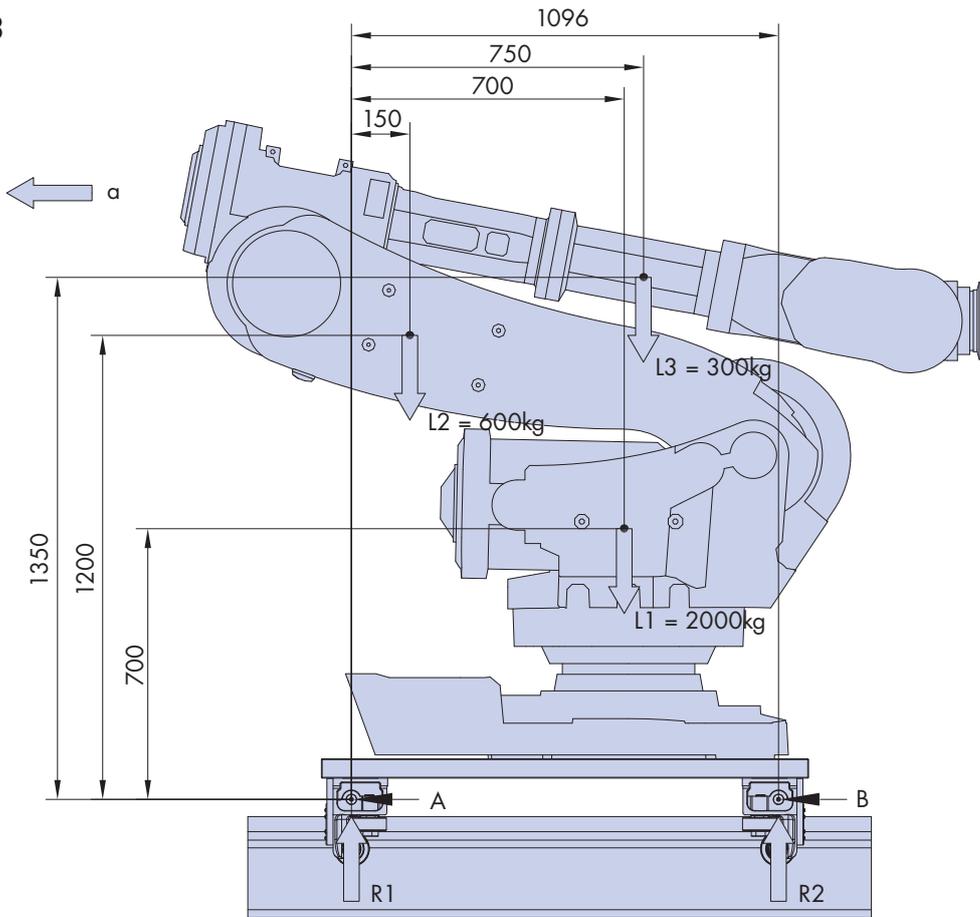
$$\text{Upper bearing life (km)} = 1000 \times \left( \frac{L_{1A(\max)}}{L_{1A}} \right)^{3.3} = 7760 \text{ km}$$

Where  $L_{1A(\max)} = 34,000N$  and  $L_{1A} = 18273N$

In this application the system travels  $1m/s \times 60 \times 60 \times 40$  (seconds/week)  $\times 0.4$  (40% duty cycle) = 57600m or 57.6km per week. The life of the system is therefore  $7760 / 57.6 = 135$  weeks or **2.6 years**.

# MHD Load/Life Calculations

## Example 3



A MHD slide system is used in an automated environment for moving a robot along a linear axis between two workstations. When moving along the slide the robot is in its compact mode and has three centres of mass with positions and values as shown in the diagram. All centres of mass lie on a common plane which is central relative to the width of the carriage. The robot accelerates at  $a_1$  ( $=1\text{m/s}^2$ ) until reaching a maximum speed of  $3\text{m/s}$ . It maintains this constant speed until decelerating at  $a_2$  ( $=0.4\text{m/s}^2$ ) to a stop. For the return journey the system runs at an average speed of  $0.5\text{m/s}$ , where the magnitudes of the accelerations are negligible and are ignored for the purposes of this example. The system has a stroke of  $20\text{m}$ . This traversing cycle runs on a  $35\%$  duty cycle for 40 hours per week. If we assume that the bearings are well within their static loading capacities when the robot is working at each station then the life of the system is going to be determined by the most highly loaded bearings during the traversing cycle.

A quick study of the diagram suggests that R2 will be the larger reaction force when the system is travelling at a constant speed and when the system is accelerating in the direction of the arrow.

**Stage 1:** calculating the reaction forces when the system is accelerating in the direction of the arrow.

[summing all forces]	$R1 + R2 = L = (2900\text{kg} \times g) = 28449\text{N}$
[taking moments about A]	$R2 \times 1.096 - (0.15\text{m} \times 600\text{kg} \times g) - (0.7\text{m} \times 2000\text{kg} \times g) - (0.75\text{m} \times 300\text{kg} \times g) - (0.7\text{m} \times 2000\text{kg} \times a_1) - (1.2\text{m} \times 600\text{kg} \times a_1) - (1.35\text{m} \times 300\text{kg} \times a_1) = 0$
[re-arranging above]	$R2 = 19349 / 1.096 = 17654\text{N}$
[substituting in first equation]	$R1 + 17654 = 28449\text{N} \therefore R1 = 10795\text{N}$

Where  $g$  = acceleration due to gravity ( $9.81\text{m/s}^2$ )

$a_1$  = acceleration of system ( $1\text{m/s}^2$ )

Both R1 and R2 are supported by two bearing blocks, so each block experiences half the load. The most heavily loaded block therefore experiences a load of  $17654 / 2 = 8827\text{N}$ .

# MHD Load/Life Calculations

**Stage 2:** calculating the reaction forces when the system is travelling at a constant velocity

[summing all forces]	$R1 + R2 = L = 28449\text{N}$
[taking moments about A]	$R2 \times 1.096 - (0.15\text{m} \times 600\text{kg} \times g) - (0.7\text{m} \times 2000\text{kg} \times g) - (0.75\text{m} \times 300\text{kg} \times g) = 0$
[re-arranging above]	$R2 = 16824 / 1.096 = 15350\text{N}$
[substituting in first equation]	$R1 + 15350 = 28449\text{N} \therefore R1 = 13099\text{N}$

Both R1 and R2 are supported by two bearing blocks, so each block experiences half the load. The most heavily loaded block therefore experiences a load of  $15350 / 2 = 7675\text{N}$ .

It can be seen that there is a change in the reaction forces as the system accelerates, in this example R2 increases by approximately 15% during the acceleration period. These reaction forces will be the same for the return journey of the traversing cycle since the entire stroke is assumed to be covered at a constant velocity of 0.5m/s.

**Stage 3:** calculating the reaction forces when the system is decelerating to a stop.

[summing all forces]	$R1 + R2 = L = (2900\text{kg} \times g) = 28449\text{N}$
[taking moments about A]	$R2 \times 1.096 - (0.15\text{m} \times 600\text{kg} \times g) - (0.7\text{m} \times 2000\text{kg} \times g) - (0.75\text{m} \times 300\text{kg} \times g) + (0.7\text{m} \times 2000\text{kg} \times a_2) + (1.2\text{m} \times 600\text{kg} \times a_2) + (1.35\text{m} \times 300\text{kg} \times a_2) = 0$
[re-arranging above]	$R2 = 15814 / 1.096 = 14429\text{N}$
[substituting in first equation]	$R1 + 14429 = 28449\text{N} \therefore R1 = 14020\text{N}$

Both R1 and R2 are supported by two bearing blocks, so each block experiences half the load. The most heavily loaded block therefore experiences a load of  $14020 / 2 = 7010\text{N}$ .

**Stage 4:** calculating an average loading on the bearings in order to calculate the life of the system.

It can be seen that it is the top bearings on the right hand side of the diagram which are subjected to the highest loading conditions during the traversing cycle. Since the loading on the top bearings changes over the traversing cycle it is necessary to calculate an average loading based on the time fractions relating to the different loading values. This average loading can then be used to calculate the life of the system.

Where the load varies, the average load is calculated as follows:

$$F_m = \sqrt[3.3]{F_1^{3.3} \times \frac{q_1}{100} + F_2^{3.3} \times \frac{q_2}{100} + F_3^{3.3} \times \frac{q_3}{100}}$$

Where  $F_m$  = average load  
 $q$  = time fraction (%)

To calculate the time fractions we need to calculate the time spent accelerating, the time spent decelerating and the time spent at constant speed and then express these as percentages of the total time to complete the traversing cycle.

The time spent accelerating,  $t_1$ , is calculated using the following equation of motion:

$$v = u + at$$

Where  $v$  = final velocity  
 $u$  = initial velocity  
 $a$  = acceleration  
 $t$  = time

Re-arranging the above equation and substituting values gives:

$$t_1 = (3\text{m/s} - 0\text{m/s}) / 1\text{m/s}^2 = 3\text{s}$$

The time spent decelerating,  $t_2$ , is calculated using the same equation of motion and is found to be 7.5s

The time spent at constant velocity,  $t_3$ , is the sum of the time spent at constant velocity on the outward and return journeys. The time spent at constant speed on the return journey can be simply calculated using the following equation of motion:

$$t = s / v$$

Where  $v$  = velocity  
 $s$  = distance

Substituting values into the above equation gives:

$$t_r = 20\text{m} / 0.5\text{m/s} = 40\text{s}$$

# MHD Load/Life Calculations

In order to calculate the distance travelled at constant velocity on the outward journey we need to calculate the distance travelled when the system is accelerating / decelerating and subtract this value from the stroke. The distance travelled when the system is accelerating is calculated using a third equation of motion:

$$v^2 = u^2 + 2as$$

Where  $v$  = final velocity

$u$  = initial velocity

$a$  = acceleration

$s$  = distance

Re-arranging the above equation and substituting the values gives:

$$s_1 = (3^2 - 0^2) / 2 \times 1 = 4.5\text{m}$$

Similarly the distance travelled whilst decelerating is found to be  $s_2 = 11.25\text{m}$

The distance at constant speed is therefore  $s_3 = 4.25\text{m}$  ( $20\text{m} - (4.5 + 11.25\text{m})$ ) and the time spent at constant speed on the outward journey is to =  $1.4\text{s}$  ( $4.25\text{m} / 3\text{m/s}$ ).

Thus the total time spent at constant velocity is  $t_3 = 41.4\text{s}$  ( $= t_r + t_d$ ) and the time to complete one traversing cycle is  $51.9\text{s}$  ( $= 3\text{s} + 7.5\text{s} + 41.4\text{s}$ )

The time fractions can now be calculated and are as follows,  $q_1 = 6\%$  ( $3\text{s} / 51.9\text{s} \times 100$ ),  $q_2 = 14\%$  ( $7.5\text{s} / 51.9\text{s} \times 100$ ) and  $q_3 = 80\%$  ( $41.4\text{s} / 51.9\text{s} \times 100$ ).

Substituting the values into the equation for average load:

$$F_m = \sqrt[3.3]{8827^{3.3} \times \frac{6}{100} + 7010^{3.3} \times \frac{14}{100} + 7675^{3.3} \times \frac{80}{100}} = 7673\text{N}$$

Using the equation for life for the top bearing the life in km is found to be:

$$\text{Upper bearing life (km)} = 1000 \times \left( \frac{L_{1A(\text{max})}}{L_{1A}} \right)^{3.3} = 135,986\text{km}$$

Where  $L_{1A(\text{max})} = 34,000\text{N}$  and  $L_{1A} = 7673\text{N}$

In this application the system travels  $[60 \times 60 \times 40 \text{ (seconds/week)} \times 0.35 \text{ (35\% duty cycle)}] / 51.9\text{s}$  (cycle time) = 971 cycles per week. Each cycle is 40m, thus the system travels 38.8km per week. The life of the system is therefore  $135,986 / 38.8 = 3505$  weeks or **67.4 years**.

## Note

For calculations where the side or the lower bearings are the most heavily loaded in a dynamic system, a power factor of 3 is substituted for 3.3 in the above equation for average load giving:

$$F_m = \sqrt[3]{F_1^3 \times \frac{q_1}{100} + F_2^3 \times \frac{q_2}{100} + F_3^3 \times \frac{q_3}{100}}$$

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