Rope Sheave
Design and Specification Guide

MITSUBISHI CHEMICAL GROUP

With more than 80 years of experience, 46 branch offices in 19 countries, and a team of technical service experts, engineers, and application development managers, the Advanced Materials Division of Mitsubishi Chemical Group (MCG) is the global leader for researching, developing, and manufacturing high-performance engineered polymer materials. Our products make the world a safer place by providing solutions across all industries- aerospace, renewable energy, chemical / oil & gas processing, food processing and packaging, construction / heavy equipment, linings, medical / life sciences, semiconductor, transportation / rail.

Values based on the sustainable well-being of people, society, and our planet earth - we call it KAITEKI

Table of Contents
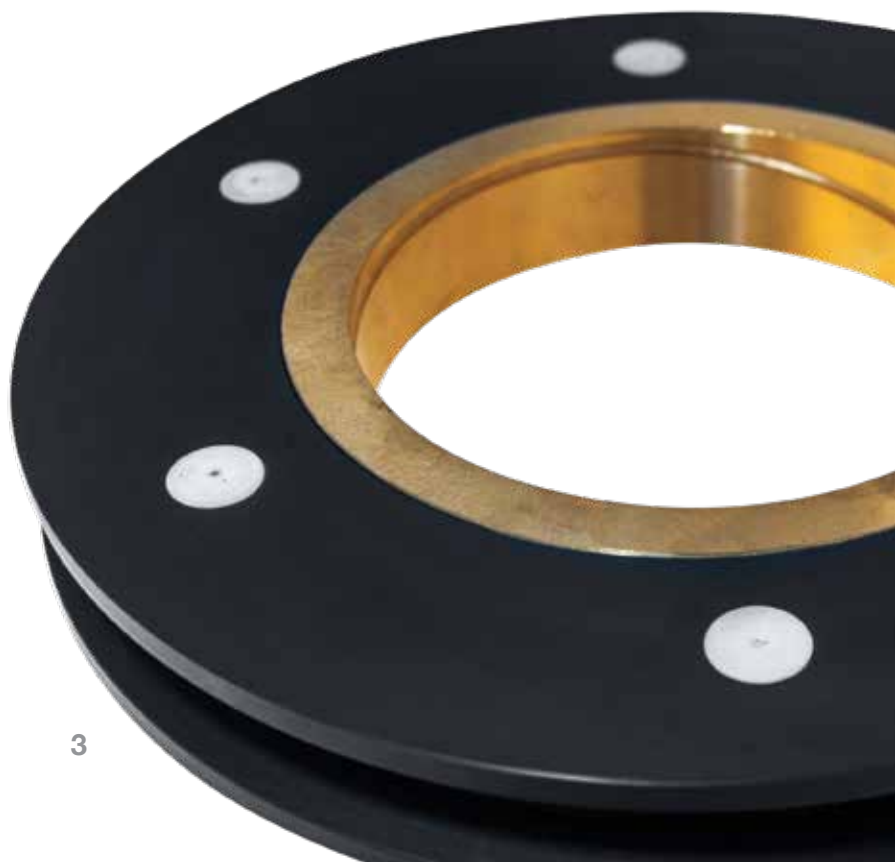
For many years, manufacturers and operators of heavy-duty lifting equipment have sought ways to increase wire rope endurance life. Early attempts included lining the grooves of metal sheaves with resilient materials and mounting rims made of these materials on metal hubs. Growth in manufacturing of mobile lifting equipment now requires designers to consider reducing the dead weight of metal sheaves on the boom or mast, and improving lift and over-the-road performance. Expansion in offshore exploration has also generated a need for lifting equipment with corrosion resistant parts.

With the development of Nylatron® GSM PA6 cast nylon sheaves, the search for improved wire rope life, reduced weight, and corrosion resistance has been resolved. Nylatron® GSM PA6 sheaves are widely used on both mobile and offshore lifting equipment.

Nylatron® GSM PA6 Sheaves

Support the same load as metal

Stress on the wire rope – not the sheave – commonly limits the lifting capacity of a system. The point contact pressure for a steel sheave will be much higher than for a Nylatron® GSM PA6 sheave, and the resilience of nylon results in a larger point contact area and creates support for the wire rope. Lightweight Nylatron® GSM PA6 sheaves can support cyclical loads equal to steel sheave capabilities.

Reduce weight

Because Nylatron® GSM PA6 nylon is approximately one seventh (1/7) the weight of conventionally used cast steel, Nylatron® GSM PA6 sheaves reduce dead weight at the end of the boom. This provides mobile cranes with greater stability and lifting capacity and lowers over-the-road weight.

The reduced weight of Nylatron® GSM PA6 sheaves makes handling, installation and replacement significantly easier and safer than with comparable metal sheaves.

Extend wire rope life

MCG Advanced Materials Division, in conjunction with a nationally recognized independent research institute, conducted wire rope endurance

tests to obtain a comparison of the fatigue life of wire rope used with Nylatron® GSM PA6 sheaves and hardened steel sheaves under the same conditions. Test results at stress levels of 10%, 20%, and 28.6% of ultimate wire rope strength indicate dramatic improvements in the endurance life of wire rope when used with cast Nylatron® GSM PA6 sheaves. Figure 1 summarizes results of the wire rope life testing. The tests prove Nylatron® GSM PA6 sheaves substantially increase rope cycle life.

Figure 1: Wire Rope Lift Test Results*

Sheave Ratio	Rope Tension Test	Design Factor	Duration of Test	Increase in Rope Life**
24/1	10.0% of breaking strength	10.0	136,000 cycles	4.50 times
24/1	20.0% of breaking strength	5.0	68,000 cycles	2.20 times
24/1	28.6% of breaking strength	3.5	70,000 cycles	1.92 times
24/1	28.6% of breaking strength	3.5	39,000 cycles	1.33 times

Sheave Ratio = D_p / D_r = Sheave pitch diameter/rope diameter

* Conventional rope retirement criteria based only upon visible wire breaks may prove inadequate in predicting rope failure. Retirement criteria should be established based on the users' experience and demands of the specific applications for users of Nylatron® nylon sheaves.
** Increase in rope life attained with Nylatron® GSM PA6 compared to hardened steel sheaves.

Resists corrosion

The corrosion resistant properties of nylon make these plastic parts ideal for marine use.

Bronze bearings are not recommended for main load applications. Their use should be limited to moderate unit loads to avoid excessive frictional heat build-up and possible movement of the bearing in the bore.

For lightly loaded applications where pressure-velocity (PV) values are not excessive, it may be possible to plain bore Nylatron® GSM PA6 sheaves for running directly on the shaft. Contact Contact MCG Advanced Masterials for appropriate running clearance information.

Design Guidelines

When designing with custom or standard sheaves, certain considerations should be observed by equipment engineers. Of special importance are groove configuration, bore configuration, bearing retention, and load capacity. The basic design of any sheave should conform to the appropriate minimum pitch diameter/rope diameter sheave ratios of 18/1 for the mobile crane industry. The minimum of 18/1 ratio conforms to the International Standards for load hoisting cranes; the preferred ratio by the Industry is 24/1 though.

Rim dimensions

The rim width (W_r), outside diameters (D_O), and tread diameters (D_t) are typically fixed design dimensions. The rim flat (F_r - shown in Figure 2) between the groove wall and rim edge should be a minimum of 3mm (0.12") to provide adequate side load stability.

Groove dimensions

For optimum rope life, the sheave groove profile should be correctly matched to the rope diameter (D_r).

If the groove is too small, the rope will be "pinched" as it is forced into the groove under the influence of load, thus damaging both the rope and the sheave. If the groove is too large, there could be insufficient support for the rope, which can become flattened and distorted under load, thus accelerating rope deterioration. The groove radius, R_g, should lie within the range $0.525D_r$ to $0.550D_r$, with $0.5375D_r$ as the optimum, where D_r is the nominal rope diameter.
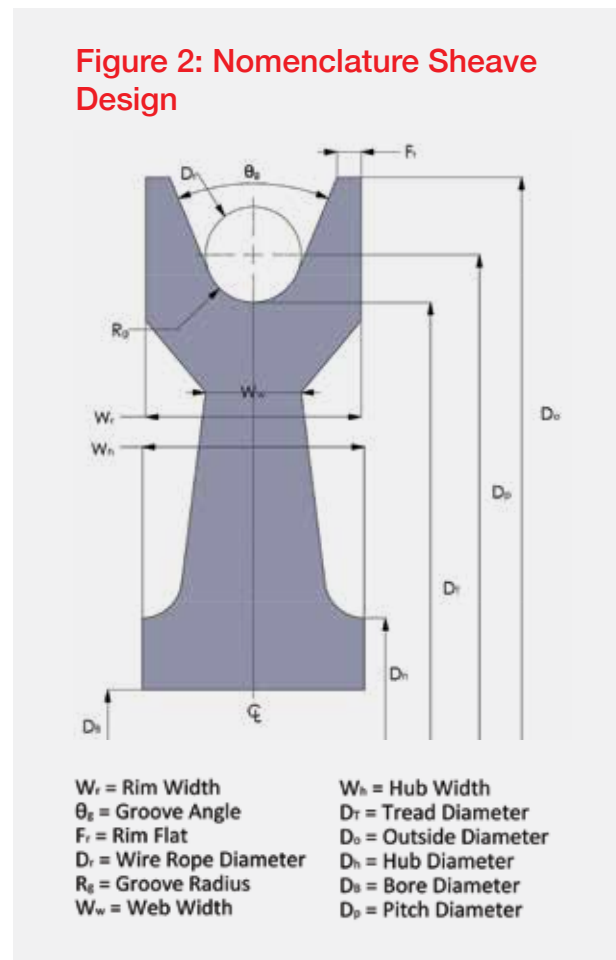
Sheaves should have a smoothly finished groove, free from ridges, of groove depth not less than 1.5 times the nominal rope diameter (preferred groove depth >1.75 times the rope diameter). The profile at the bottom of the groove should be circular. The angle between the sides of the sheave, Θ_g, (see Figure 2) should be between 30° and 60° which is depending on the fleet angle (see Figure 3).
The following is recommended:

Fleet Angle 0-1°, groove angle at least 30°
Fleet Angle 2-3°, groove angle at least 45°
Fleet Angle 4-5°, groove angle at least 60°
Fleet Angles of >5° are not recommended.

Web Dimensions

Practical experience with crane sheaves has shown that the required design strength can be

Figure 2: Nomenclature Sheave Design

W_r = Rim Width
θ_g = Groove Angle
F_r = Rim Flat
D_r = Wire Rope Diameter
R_g = Groove Radius
W_w = Web Width

W_h = Hub Width
D_T = Tread Diameter
D_o = Outside Diameter
D_h = Hub Diameter
D_B = Bore Diameter
D_p = Pitch Diameter

maintained with a minimum web width (W_w) that is at least 20% greater than the rope diameter or:

$W_w \geq 1.20 \cdot$ Rope Diameter. The benefit of reducing the web width is weight savings. Additional strength can be obtained by adding ribs to the design.

Hub Dimensions

The hub width (W_h) is generally a design requirement specified by the end user. In most cases it should be equal to or greater than the rim width (W_r) for stability of the sheave in use. The minimum hub diameter (D_h) is 1.5 times the bearing outside diameter (D_b) for adequate wall support of the bearing. The wall thickness between the bearing and hub diameter should always be greater than 25mm.

$D_h = 1.5(D_b)$

Bore Dimensions

Nylatron® GSM PA6 sheaves for heavy-duty applications should be installed with anti-friction bearings. Needle or cylindrical roller bearings are generally recommended, as they provide a continuous contact area across the width of the bore.
As the coefficient of thermal expansion of nylon is several times that of metal, the press fit allowance must be large enough for the bearing to maintain contact with the bore at temperatures up to 50°C (120°F). This is calculated by:

$d = 0.045\sqrt{D_b}$
Where: d = Press fit allowance (mm)
$\quad\quad\quad$ D_b = Bearing outside diameter (mm)

$d = 0.009\sqrt{D_b}$
Where: d = Press fit allowance (in)
$\quad\quad\quad$ D_b = Bearing outside diameter (inch)

The diameter of the sheave bore will be the O.D. of the bearing minus the press fit allowance.
The tolerance field is +0 and -0.10 mm (+0 and -0.004").

$D_B = D_b - d$ +0/-0.10mm (+0/-0.004")

Sufficient press fit is critical to prevent buckling of a loaded sheave.

For lightly loaded applications where pressure velocity (PV) values (indication for the amount of heat which is generated) are not excessive, it may be possible to plain bore Nylatron® GSM PA6 sheaves for running directly on the shaft. Please consult MCG Advanced Materials to discuss and calculate these possibilities.

Figure 3
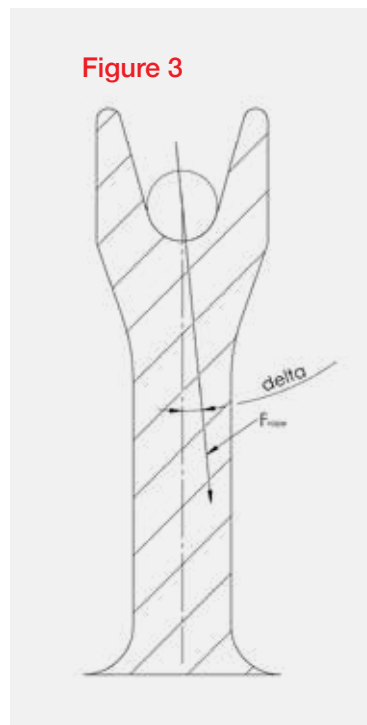
Bearing Retention

Circumferential bearing retention can be achieved using the press fit allowances (as calculated under bore dimensions) and pressing directly into the bore of the Nylatron® GSM PA6 sheave.
A hydraulic press can be used, or the sheave can be heated to 80°-90°C (180°-200°F) where after you can easily assemble the bearing into the expanded bore. Thrust washers, thrust plates or snap rings should be placed on either side of the sheave hub to maintain sideways bearing retention. This is necessary to restrict bearing movement which may occur as the result of side forces encountered during operation.

There are two exceptions to bearing retention using the previous procedure:

• Bronze bearings in idler sheaves where the sheave is free to move from side-to-side on a shaft. In this case, positive retention can be accomplished by extending the length of the bearing beyond the hub and placing external rings on the bearing on each side of the hub

• Under conditions where the use of steel inserts are recommended due to heavy loading. A positive retention method is to place a steel sleeve insert in the bore of the sheaves into which the bearing is pressed. The insert is held in the bore by external retaining rings on each side of the hub.

If thrust plates or thrust washers cannot be used, other means of retention must be found to restrict sideways movement of the bearing. Metal side plates bolted to the hub and overlapping the ends of the bearing can also be used for this purpose.

Load Capability of Nylatron® GSM PA6 Sheaves

Load capability with bearings

When Nylatron® GSM PA6 sheaves are used in heavy-duty service, the user should first determine the sheave ratio and design factor which are appropriate for the application. Using specific values for the variables, nominal static pressures can be calculated for evaluation of sheave load carrying capacity.

The equations to the right can be used to calculate the maximum groove and bore pressure acting on any sheave.

Equation 1: Maximum Groove Pressure

$$P_g = \frac{2\,(LP_{MAX})}{D_r \cdot D_t}$$

Equation 2: Maximum Bore Pressure

$$P_b = \frac{2\,(LP_{MAX})\,K_\Theta}{D_b \cdot W_{bearing}}$$

Where: P_g = Max groove pressure (MPa or PSI)

$\qquad$ P_b = Max bore pressure (MPa or PSI)

$\qquad$ LP_{MAX} = Max single line pull (N or lb) or wire rope breaking strength divided by design safety factor

$\qquad$ D_r = Rope diameter (mm or in)

$\qquad$ D_t = Tread diameter / groove base diameter (mm or in)

$\qquad$ D_b = Bore diameter (mm or in)

$\qquad$ $W_{bearing}$ = total sum of individual bearing width in contact with the sheave (mm or in)

$\qquad$ K_Θ = Wrap factor = $\sin\left(\dfrac{\text{wrap angle}}{2}\right)$

Be aware Equation 2 (bore pressure) is only applicable when the fleet angles (see Figure 3) are 0°, when > 0° one should calculate the loading in axial direction (sidewards pull due to this fleet angle) as well (please consult MCG Advanced Materials for further detailed calculations).

As known, nylon or any other thermoplastic material tends to creep under load. For the press fit between a roller bearing and a nylon sheave this can lead to problems. When the bearing outer ring starts to move inside the nylon sheave this could lead to further loosening of the press fit and finally result in a failure of the sheave - bearing connection.


Figure 4: Wrap Angle

To investigate the creep of the bearing bore in a nylon sheave as function of the load, the MCG Advanced Materials Division executed a test on the so called 'saw test-machine' as shown in Figure 5.

The test machine consists out of a HEA beam welded to 2 workshop supports. There are two identical hydraulic cylinders attached to each flange of the HEA beam. These cylinders apply line pull on a wire rope. This wire rope runs over a test sheave. The object that is tested is an ø510 [mm] rope sheave, made from Nylatron® GSM PA6 nylon. The sheave is suitable for use with an ø24 [mm] steel wire rope. Groove angle is 45° and groove radius is R12.5 [mm]. See Figure 6 of the test sheave.
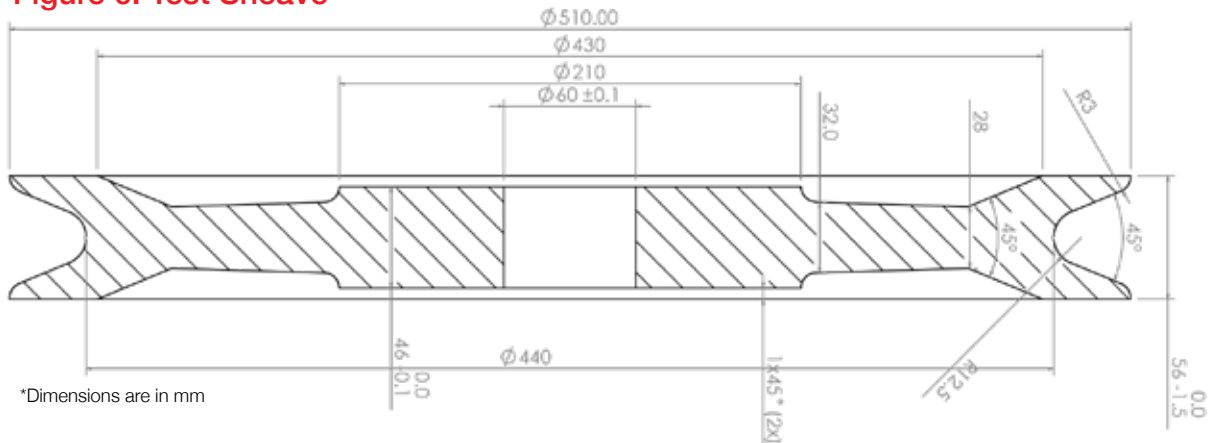
Figure 5: Saw Test Machine
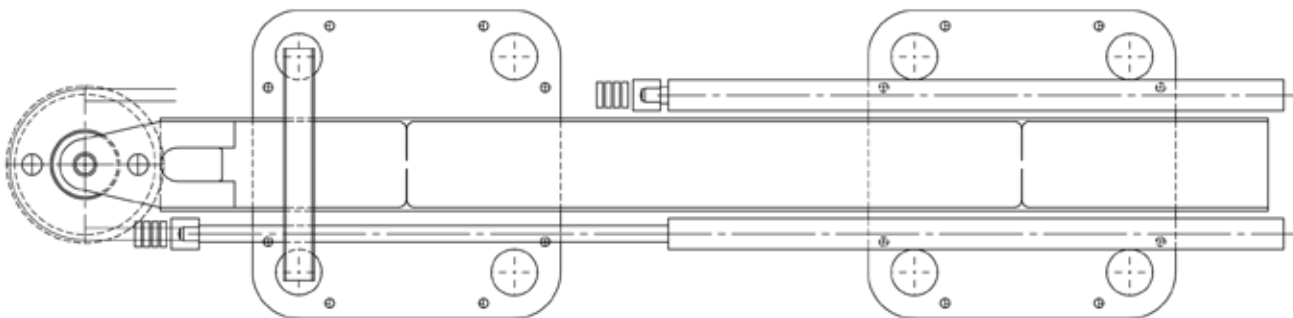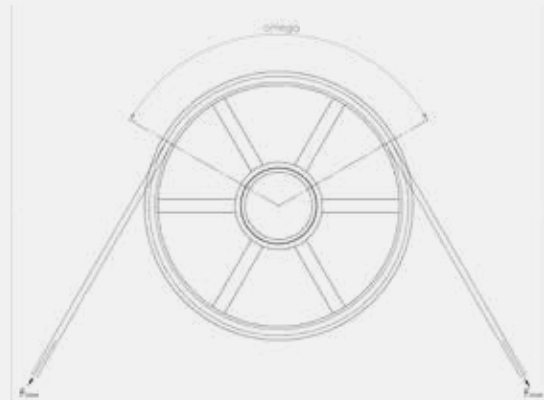
Figure 6: Test Sheave*

*Dimensions are in mm

Static tests with a constant line pull, where the deformation around the bearing hole is measured as a function of time, is executed at different time intervals. The line pull is decreased in steps in order to determine the maximum allowable line pull. The overall outcome is interpreted and shown in Figures 7 and 8.

Figure 7: Maximum Allowable Static Surface Pressure in Bore in Function of Time at Maximum Temperature of 50°C (120°F)
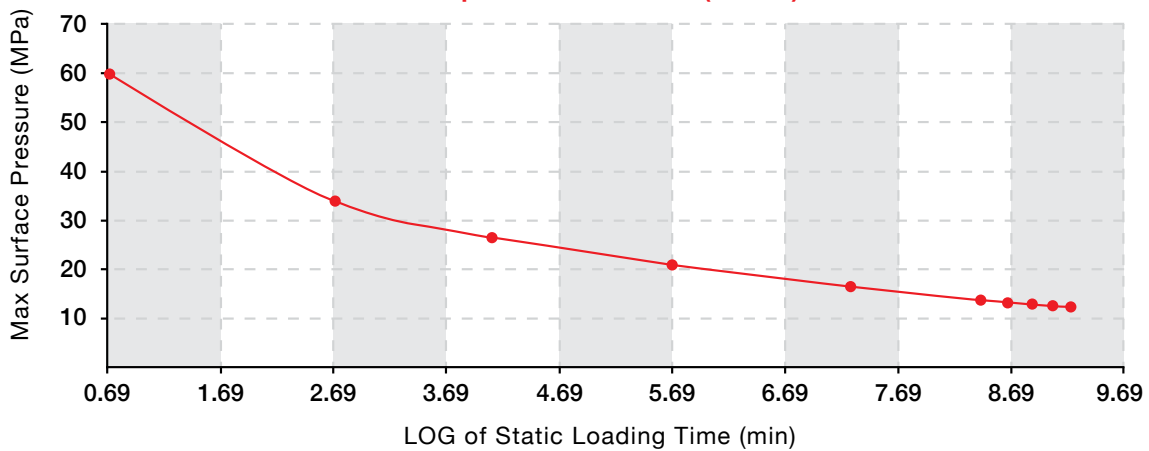
Figure 8: Pressure Limits

Time of Static Loading (= no rotation)	Maximum Surface Pressure (MPa) at Maximum 50°C
2 minutes maximum	60
15 minutes maximum	34
60 minutes maximum	27
5 hours maximum	21
1 day maximum	17
3 days maximum	14
4 days maximum	13
5 days maximum	13
6 days maximum	13
7 days maximum (= 1 week)	12

Load capability of plain bored sheaves

The load capacity for a plain bored Nylatron® GSM PA6 sheave is based upon the ability of the bore to act as a bearing. To determine the recommended load capacity, refer to the Bearing Design manual of MCG Advanced Materials, and make calculations assuming that the bore of the sheave is a Nylatron® GSM PA6 bearing (please consult our technical service department for further detailed calculations).

Specifications

Sheave lifetime

When Nylatron® rope sheaves are used, they eventually need to be replaced due to change of geometry effects (wear and deformation) and material effects (material degradation). The combination of these effects will determine the lifetime.

Sheaves should be inspected at least every 6 months regarding damage, cracks, wear and deformation. Sheave lifetime can be negatively influenced by:

  • Wrong bearing. MCG Advanced Materials advices clearance class minimum C3

  • Wrong cable. MCG Advanced Materials advices to use rotation-resistant ropes.

  • Fleet angle too big, causing the sheave to deflect or break. The following is recommended:
    Fleet Angle 0-1°, groove angle at least 30°Fleet Angle 2-3°, groove angle at least 45°Fleet Angle 4-5°, groove angle at least 60°

Figure 9: Thickness T1 in Worn Sheave

Minimum 60% of cable diameter

Wear and deformation

Nylatron® rope sheaves are designed as idle pulleys. However due to friction in the bearings and acceleration of the cable, the initial cable speed may differ from the sheave speed. This will cause a sliding effect and could cause higher wear. Groove depth is easy to measure but will not indicate wear in axial direction of the groove. Therefore, MCG Advanced Materials recommends using T1, which is the minimum wall thickness of the flange (see Figure 9). We advise to manufacture sheaves with a T1 between 80% and 100% of the nominal cable diameter and sheaves should be replaced when it has been reduced to about 60% of the nominal cable diameter. When a rope sheave is overloaded, elasticity limit is exceeded and plastic deformation will occur. When sheaves show signs of buckling or deformation in the bore, a sheave must be replaced immediately.

Material degradation

Polyamide is a strong engineering plastic, but mechanical properties deteriorate due to environmental effects, time under load, UV degradation, temperature and/or moisture.

- Due to the risk of creep, caused by long term static loads, loading time and conditions should be known at time of designing a sheave. Generally sheaves are calculated for use in dynamic conditions, meaning that the sheave will keep rotating and only stop shortly when subjected to high loads.

- Mechanical properties will vary with temperature: below –25°C (–13°F) the material is very stiff and becomes more brittle, above +50°C (120°F) the material becomes quite flexible and buckling may occur.

- Absorption of moisture out of surrounding air is a very slow process. Since this penetration starts at the outside surface, it will (dependent on the cross section) take more than 10 years before the core is saturated. Sheave stiffness will reduce, but toughness will increase due to the absorbed water.

- UV radiation will stop at the outside surface of the material and cannot penetrate deep into the material.

- Sheaves are designed according to the circumstances mentioned above. Changing circumstances need to be verified or communicated to the MCG Advanced Materials Division.

Cleaning and chemical resistance

Sheaves can be cleaned, but one should be careful with chemicals. Also cleaning with hot water could result in accelerated moisture absorption.

A summary of chemical resistance at 23°C (73°C) is given on this page. A separate brochure with an extended list is available upon request.

Resistant:
- Both aromatic and aliphatic hydrocarbons (petroleum, petrol, kerosene, diesel fuels)
- Weak alkali's
- Ketones, esters and ethers
- Inorganic salt solutions
- Mineral oils and greases

Partially resistant:
- Weak acids
- Chlorinated solvents

Not resistant:
- Strong mineral and organic acids
- Strong alkali's

Maintenance

Initially, bearings are assembled using a press fit interference and in almost all cases, snap rings (circlips) or other retaining systems (like flanges), in addition. During the disassembly and later assembly of a new bearing, perfect alignment and supporting of the sheave hub must be assured to prevent permanent deflection/deformation of the sheaves or the bore.

Conclusion

- Standard Nylatron® rope sheaves can be used in temperature range of –25°C (–13°F) up to +50°C (120°F). Material for other temperature ranges is available upon request.

- Nylatron® sheaves can standard be used in relative humidity of 30% - 70%.

- In normal use, the lifetime of Nylatron® sheaves is minimum 10 years.

- Nylatron® rope sheaves are designed for dynamic loading; long term static loading should be avoided.

Information Required

	Maximum single line pull (Load)	Newton (lbs.)
	Line speed	m/s (ft./min.)
	Fleet angle	°
	Temperature low	°C (°F)
	Temperature high	°C (°F)
	Wrap Angle (Arc of sheave contacted by rope)	°
Sheave Data	Drawing Number?	
	If no drawing is available:	
	W_r Rim width:	mm (in)
	D_o Outer diameter:	mm (in)
	D_t Tread diameter	mm (in)
	D_h Center hub O.D.	mm (in)
	W_h Hub width	mm (in)
	D_b Center bore I.D.	mm (in)
	Alignment or access holes required?	
	Number?	
	Pitch Circle?	
	Grease fittings?	
	Type?	
	Location?	
Wire Rope Data	Rope O.D	mm (in)
	Rated breaking strength	
	Brand of rope in use	
Bearing Specifications	Design	
	Mfr / Part Number	
	O.D. of outer race	mm (in)
	Bearing width	mm (in)
	Method of attachment	

If you require any further assistance, contact the MCG Advanced Materials Division.

- **Contact MCG Advanced Materials Division for special design requirements including high temperature applications, sheave ratios below 18:1, fleet angles greater than 3°, or severe chemical environments. Industries that use sheaves for power transmission or load lifting applications typically have other bearing and wear requirements that could also benefit from the use of our products.**

- **The use of nylon thrust washers or plates where they will wear against the Nylatron® GSM PA6 sheave hub are not recommended.**

- **Calculation of tread (groove) pressure is normally not necessary if the ratio of groove diameter to rope diameter is 18:1 or larger.**

- **Nylatron's® wear and impact resistance, light weight, and corrosion resistance present unique advantages in a wide variety of wear and structural components (i.e. slide bearings, wire guides, bushings, rollers and roll covers).**

- **The pressure and load capacity limits recommended here are based on intermittent cyclical loading as in typical mobile hydraulic crane operation. If operation involves continuous cycling or loading, high speed and acceleration, or heavy impact forces, the limits should be reduced and the application thoroughly evaluated.**

- **Excessive loads and/or speeds may cause distortion of the bore and loss of press fit with the bearing. Accelerated groove wear may also result. For plain bored sheaves, excessive loads and/or speeds may cause accelerated wear and increased clearance in the bore.**

- **MCG Advanced Materials has an extended list of available molds for the manufacturing of Nylatron® GSM PA6 rope sheaves. Please consult the technical services department to check whether one of the "standard" sizes could be used for your intended project.**

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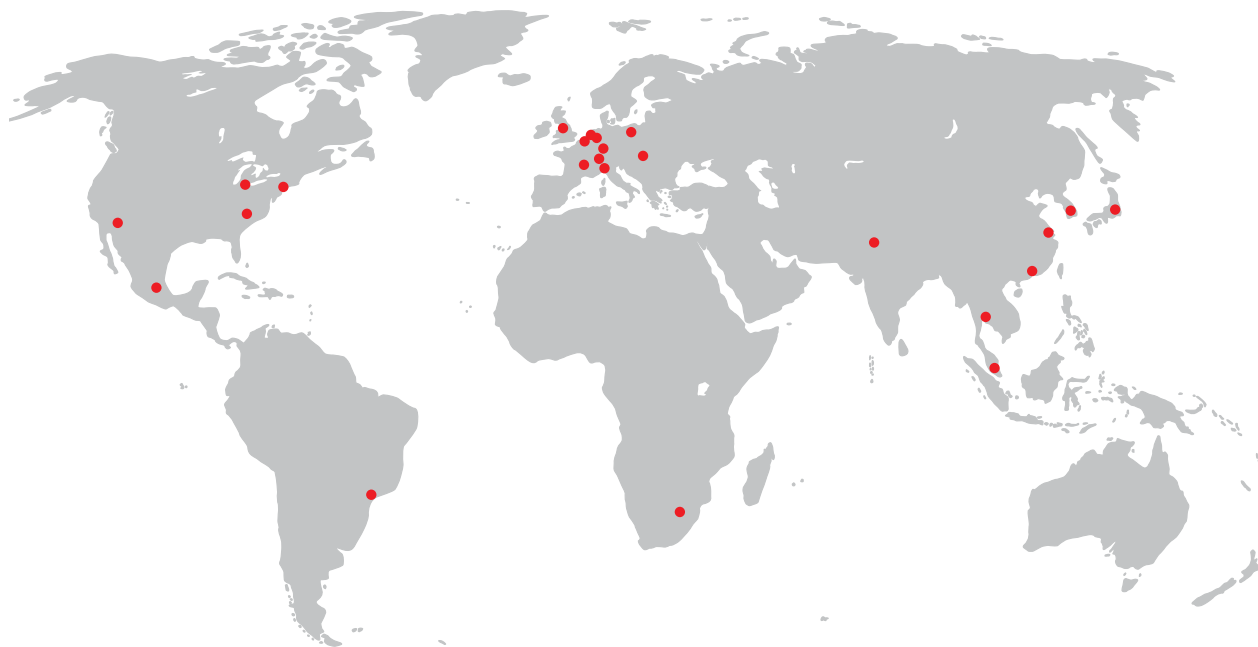F +32 (0)51 423 310

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