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FAILURE MODES OF FLEXIBLE METALLIC MEMBRANE COUPLINGS

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Abstract: *The paper describes the design of flexible metallic membrane couplings with reference to the influence of axial and angular misalignments on membrane stress. It is shown that these couplings are capable of satisfying the demand for higher powers and higher speeds with significant misalignments. The amount of misalignments is a significant cause of failure and hence the examination of parameters affecting life and safeness of the coupling is essential to ensure a proper coupling design for high speed and high torque applications.*
Key words: *flexible coupling, misalignment, failure mode*

1. INTRODUCTION

The flexible metallic couplings are systems used in power transmissions for several specific main advantages between the similar compensative couplings: great flexibility to assume the possible different deviations and high transmitted power.

These couplings connect two shafts of a kinematical chain with flexing membranes and allow the parts of the coupling to move relative to each other, while the flexing membranes stretch or bend to accept the relative motion. In this idea, the flexing membrane must be strong to transmit the high power required and must also be flexible enough to accept the deformations from misalignment without breaking and without imposing reaction forces on the connected equipment. Hence, fatigue resistance is their main performance criterion.

The flexible membranes have a spoked form, the deformation of the spokes giving the coupling its flexibility and ability to handle installation misalignments. By clamping packs of membrane together, it is possible to combine an adequate level of torque transmission with a reasonable angular and axial misalignment capability.

The coupling variant without spacer permits the taking over of the axial and angular deviations. There is a coupling variant with intermediary spacer (fig. 1) which also allows radial deformations and the taking over of the radial displacements.

The membranes unit consists of one or two membranes pockets. The membranes are rigidly assembled in pack by rivets at their inner and outer diameters. Each pack of the unit is fixed on the flanged hub by screws (bolts) on the outer diameter. These components of the coupling are not subject to the same magnitudes of stresses (Dobre, 2004).

The paper task is the stress state analysis of flexible membranes unit caused by torque, speed and misalignments, as well as failure modes of spoked membranes at gradually increasing loading conditions.

2. LITERATURE REVIEW

The references in this paper cover a particular area linked to this type of flexible couplings (Phillips et al., 1977, Phillips, 1986). Mancuso & Corcoran (2003) created the guidelines to evaluate disc and diaphragm designs for high power rotating systems. Dobre (2004) conducted an experimental program of the entire metal membrane coupling in order to simulate the flexure of a membrane rotating under angular misalignment conditions. A dedicated paper used as a basis for the considerations coming next was created by Dobre (2004).

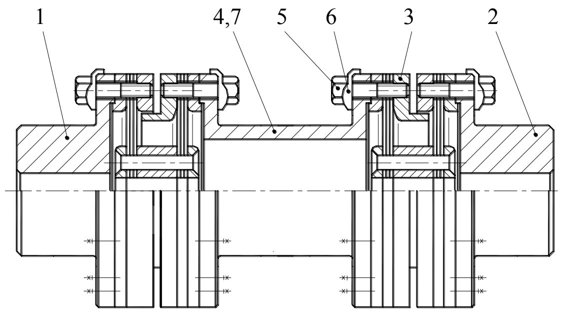

Fig. 1. Spacer coupling (1, 2 – flanged hub; 3 - membrane unit; 4, 7 - spacer; 5 - bolt; 6 – washer)

3. MEMBRANE COUPLING FAILURE MODES

The membranes pack is the heart of a flexible-element coupling and it is the most highly stressed component during continuous operation. Understanding the influence of misalignments is essential to ensure a proper coupling design for high speed and high power applications. The membrane stresses are influenced not only by torque and speed, but also by the misalignment and the adjacent components attachment method. Figure 2 shows an individual spoke of the membrane. In a coupling this spoke would be rigidly clamped at both the inner and outer diameters.

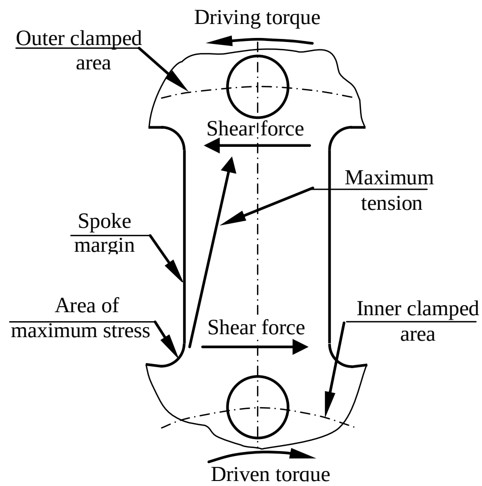

Fig. 2. Loading scheme of an individual membrane spoke

Flexible metallic membrane couplings fail in either of these two basic causes: excessive angular or radial misalignment (with or without axial displacement) or overtorque. Under normal operating conditions a coupling's membrane is subjected to uniform and cyclic stresses. The uniform stresses are generated by torque (causing shear, bending and tensile stress), centrifugal forces and axial deflection, while the cyclic stresses are induced by the angular misalignment which causes bending and tensile stress. Torque is transmitted by driving bolts and produces a tensile stress in the membrane pack members, shear and bending. It is noted that the maximum stress is adjacent to the inner diameter or root of spoke, the stress due to torque transmission, speed of rotation and misalignment deflections all being a maximum at this point.

The axial deformation of the membrane has two effects: radial stretch (the distance between the inner and outer sections of the membrane assembly increases) and bending. The stresses imposed by axial deflection are larger at the inner than at the outer diameter. These large stresses influence the membranes' failure mode (Dobre, 2004).

The dangerous membrane fatigue loading is determined by the angular deviation which produces cyclic stresses in the membranes at shaft running speed frequency. The fatigue effect of such oscillating stresses is estimated to be two or three times more destructive than the steady stress exerted by axial misalignment and torsional load. An excessive angular misalignment will produce dangerous variable solicitation that can quickly destroy the membrane unit, even when the steady stress is quite modest (Phillips et al., 1977). Under angular misalignment, the membrane bends back and forth each revolution to accommodate the equipment misalignment, therefore the membrane is subject to a combination of stretching and bending. So the failure mode is bending fatigue.

Bending is controlled by geometry of the membrane, individual membrane thickness, bolt circle diameter, overall membrane pack stiffness and number of membranes.

If misalignment is kept under ¼ degree, the flexible membrane coupling will provide a long life with little maintenance (if one or more membranes fail, the rest can still carry the load until the equipment is shut down, depending on the magnitude of the load).

If the angular misalignment increases beyond ½ degree during operation, the flexible membrane will fail in fatigue.

To understand the negative effect that have angular misalignments in relation to other misalignments (radial and axial), is considered to analysis the failure diagram of type Goodman (fig. 3), in the case of existence of two possible angular misalignments ($\Delta\alpha = 1/4°$ and $\Delta\alpha = 1/2°$).

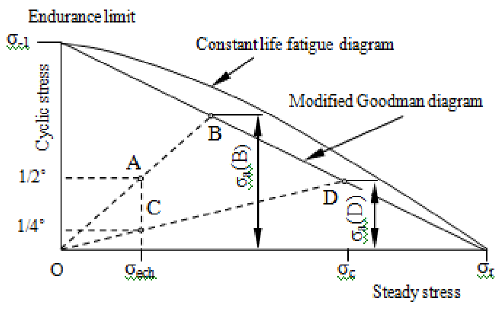

Fig. 3. Modified Goodman diagram for membrane assembly
σ_r – ultimate stress; σ_c – yield stress; σ_{ech} – equivalent stress; σ_{-1} – endurance limit

It is clear that the magnitude of cyclic stress is greater at a higher angular misalignment ($\Delta\alpha = 1/2°$), given the situation of a lower angular misalignment ($\Delta\alpha = 1/4°$): $\sigma_a(B) > \sigma_a(D)$.

For an equivalent stress caused by loading their datum points in the two cases of misalignments are: A for the deviation of 1/2° and C for deviation of 1/4°.

When the cyclic stress corresponding to 1/2° angular misalignment is added, the reserve factor is obtained from the relationship OB/OA. In figure 3 this reserve factor is $c(1/2°)=2$. If the angular misalignment is reduced from 1/2° to 1/4° the cyclic stress is reduced to a quarter of its former value and the new reserve factor becomes OD/OC which has a value of $c(1/4°)=4$. The safety factor c is given by the ratio OB/OA, where OB means failure load and OA applied load. The difference of the two loadings, represented by segment AB, defines reserve growth of loading. If the coupling was perfectly aligned, the factor of safety is over 5 and the coupling would normally have infinite life. For high speed machinery up to 7500 rpm angular misalignment should not exceed 1/3° per membrane packet whilst for speeds in excess of this a practical limit might be 1/4° (Mancuso & Corcoran, 2003). It is seen that the angular misalignment and torsional loading is designed to be approximately a quarter of the yield stress.

To analyze membrane pack behaviour, its fatigue factor of safety must be determined at different loading conditions. The basic steps that must be considered to calculate the fatigue safety factor are the following:

Step 1: Determine the normal stresses that result from the operating conditions, using classical methods (the mechanical strength criterion), numerical methods and FEA;

Step 2: Apply an appropriate failure theory such as maximum principle stress, maximum shear stress or maximum equivalent stress to represent the combined state of stress;

Step 3: Apply fatigue failure criteria that include Goodman criteria, modified Goodman criteria or constant life fatigue diagrams to establish the equivalent cyclic stress;

Step 4: Calculate the fatigue factor of safety by comparing the equivalent alternating stress to the fatigue failure strength.

The operating stresses in the flexible membrane must be designed to be under the endurance limit of the material used. Beyond this limit the material can be expected to fail after some finite number of cyclic loads. Below this limit the material can be expected to have infinite life.

4. CONCLUSION

The flexible metallic membrane couplings rely on the membrane's flexure to accommodate misalignment and axial displacement of shaft ends while transmitting torque.

The performance of the membrane type coupling is greatly influenced by the angular misalignment and by the axial displacement between shafts. The failure mode of membranes, when stressed above their endurance limit, depends on the angular misalignment and axial displacement present at the membrane. The effects of various type of misalignment (angular, lateral and axial) are additive (Mancuso, 1986).

Authors develop new researches to determine the factors of safety using the modified Goodman criteria by proportional increase in stress assumptions. The factor of safety for a particular application can be expected to generally be higher.

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