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Development of methodologies for sliding wear measurement on liners and flexible riser pipes

M.A.F. de Moraes [a], J. Bertholdi [a], R.V. Arencibia [a], F.F. Ramos Neto [b], S.D. Franco [a,*]

[a] School of Mechanical Engineering, Federal University of Uberlândia, Uberlândia, Brazil
[b] Research and Development Center, Petrobras, Rio de Janeiro, Brazil

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ABSTRACT

Flexible riser pipes are extensively used in deep-water oil and gas exploration to transport these products from the seabed to the platform. These pipes may be severely worn out on the bend stiffener region due to the reciprocating sliding movement against the liners. This relative movement is caused by water currents, bad weather conditions and platform movements. This paper presents the development of methodologies to quantify the wear rate of flexible riser pipes and of liners using a coordinate measuring machine (CMM). Samples of six-inch flexible riser pipes and of liners tested in a large-scale tribometer were used to evaluate these methodologies. The expanded measurement uncertainty of the wear parameters was assessed according to the recommendations of the “Guide to the expression of uncertainty in measurement” (GUM-JCGM 100). Moreover, the contribution of the sample elastic deformation and of the thermal effects on the measurement uncertainty was considered. Among all the factors that affect the measurement uncertainty of the wear rate of the flexible riser pipe, the variability of the thickness along the wear track contributed most to the measurement uncertainty. This variability was caused by a rough inner surface in the riser polymeric layer. When measuring the liner wear rate, the elastic deformation of the polyurethane polymer had the highest contribution. The wear rate of the six-inch riser pipe and of the corresponding liner made it possible to estimate the lifetime of these components in the field.

1. Introduction

Flexible riser pipes have been extensively used in deep-water oil and gas exploration to transport these products from the seabed to the platform. They are also used to inject water into the wells in order to recover their production capacity. Flexible riser pipes are also employed in valve control and power supply systems. In this case these pipes are called umbilicals.

The outer polymeric layer of these pipes may get severely worn out on the bend stiffener region, about 30 m below the sea level, due to reciprocating sliding movement against liners. The liners constrain the flexible pipe transversal movement, so that fatigue cracks in these pipes at the connector area are reduced.

This polymeric layer, usually made of polyethylene (PE) or polyamide (PA), may slide against different liner materials, such as steel, polyurethane (PU) or a composite material. In order to evaluate the wear performance of different material combinations, wear tests may be carried out to enable the estimation of the lifetime of the riser pipe polymer.

Considering the fact that these pipes may have large dimensions, 200 mm or more, the applicability of the current wear measurement techniques has to be evaluated. One of the most common techniques to evaluate wear is the measurement of mass loss using a scale. Other techniques are based on contact measurements, for example using a linear variable differential transformer (LVDT) or a coordinate measuring machine (CMM). Additional methods include non-contact sample scanning, before and after the wear tests, using 3D profilometers, probe microscopes or confocal, interference and focus variation microscopes [1–5].

The use of LVDT to measure thickness or volume reduction due to the wear of polymeric materials in flexible riser pipes and liners is not feasible since these materials show high elastic deformation and are prone to water absorption during the wear test. Similarly, the use of scales in evaluating wear losses of polymeric materials of large dimensions is not recommended because the mass loss usually is very low and requires scales with a resolution of 0.1 mg, as suggested by ASTM G99 [6]. Although, scales with high nominal range imply lower resolution capacity limiting the usage of scales in large samples wear tests. Additionally, LVDT and scale methods

* Corresponding author. Fax: +05534 3239 4206.
E-mail address: sdfranco@ufu.br (S.D. Franco).

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do not give any information about the wear distribution on the surface [5–7].

To overcome these difficulties CMM have been used as an alternative to measure volume loss in wear tests of hip joint prosthetic components. They allow the evaluation of wear volume and an accurate localization of wear scars [7–9]. This method is allowed by ISO 14,242-2:2000 [10] for the wear evaluation of hip joint prostheses providing information about linear wear, worn areas, and wear volume [9,10].

Bills et al. [8] evaluated the applicability of CMM in measuring the wear in explanted total hip replacement joints without having their original dimensions. The original geometry was estimated from points outside the bearing surface using non-uniform rational B-splines. This approximation can nevertheless introduce significant errors in the measured values. In their study, the measurement uncertainty was not estimated.

The uncertainties of volumetric wear loss of ceramic femoral heads were evaluated by Carmignato et al. [7] using a CMM. The wear volume and wear maps were obtained after probing the retrieved hip joint surface and estimating the original surface. The difference in volume between these two geometries gave the worn volume. These authors validated this methodology by comparing it with values obtained in the gravimetric method. Although they have listed five components of uncertainty that affect wear volume measurements using CMM, only the uncertainties associated with the CMM probing system and the one related to the implemented measurement strategy were investigated. These authors assumed these uncertainties to be the greatest contribution in the measurement uncertainty. It is known that the measuring strategy, especially the number of points probed and their distribution on the part surface, can significantly influence the final results and the measurement uncertainty [11].

Bills et al. [12] showed that the magnitude of expanded measurement uncertainty is vital, when measuring the wear geometry of retrieved bearings with a CMM, as a means of comparison between studies and as a degree of confidence in measurement data. They found that the measurement uncertainty can be of the same order as the wear being measured.

All these studies are based on the dimensional changes of hip components that are usually smaller than 50 mm and have a spherical geometry [7–9,12], so that the use of this measurement strategy on large flexible riser pipes with significant form deviations (straightness, waviness and roughness) and liners with freeform surface requires a systematic evaluation.

In the case of hip joints, the number of probed points, which is a function of the point pitch and the scan line pitch, may vary from a few hundred to a few thousand, thus facilitating the data manipulation and the substitute geometry fit. However, to evaluate the wear of larger parts with a freeform surface, the number of probed points is considerably increased making this task extremely complex. The reasons that may contribute to increase this complexity are: a) risers and liners are usually made of polyamide (PA) and polyurethane (PU), respectively, leading to worn surfaces with high surface roughness values; b) low geometric and dimensional repeatability of samples; c) elastic deformation at the contact point (sample-probe) during measurement in the CMM; d) a significant amount of polyurethane particles are not totally detached from the worn surface, leading to measuring points which in other applications, could be considered as outliers and therefore eliminated, but in this particular case, these points must be preserved.

This study aims to develop methodologies to quantify the wear of flexible riser pipes and of liners that were tested in a large-scale tribometer. These measurement methodologies were based on probed points obtained using a CMM. To determine the volume and the thickness losses of the liner samples using the coordinates of probed points, a software based on the trapezoid method was developed. The expanded measurement uncertainty was assessed following the recommendations of the "Guide to the expression of uncertainty in measurement" (GUM-JCGM 100) [13], considering even the elastic deformation of the sample during the probing action and the thermal effects.

2. Experimental procedure

Samples of flexible riser pipes with an internal diameter of four (101.6 mm) and six (152.4 mm) inches with a polymeric protecting layer of PA were tested for a long period of time by sliding against PU liner samples in a large-scale tribometer (Fig. 1). This test rig was designed to reproduce the reciprocating sliding wear configuration observed in oil and gas platforms in the bend stiffener region. The riser pipe sample was set in a reciprocating vertical movement by two hydraulic cylinders, while two similar samples of the liner were pressed against the pipe by two other horizontal hydraulic cylinders. The stroke was only 30 mm long, so that the center of the contact area of both samples did not get in touch with water (Table 1).

In order to determine wear rates of the liner and of the riser pipe, a moving bridge Coordinate Measuring Machine (CMM), manufactured by Carl Zeiss, model Contura G2 RDS/XXT, was used. This CMM has a resolution of 0.2 μm and a work volume of 1000 mm (X axis) 1200 mm (Y axis) and 600 mm (Z axis). According to the calibration certificate, the CMM used in the measurements has linear expanded measurement uncertainty of $0.7+L/278$ μm with a coverage factor k of 2.00 and 95% of coverage probability. The probing error is 0.2 μm.

The surfaces of the four-inch riser pipe and of the liner were assessed using an articulating probe holder and a single tip with a 3 mm diameter ruby ball and a stem of 50 mm in length. The six-inch liner was measured using a 2 and 3 mm ruby ball tip with a stem length of 20 and 50 mm, respectively. The probing force on the ruby ball tip was 200 mN.

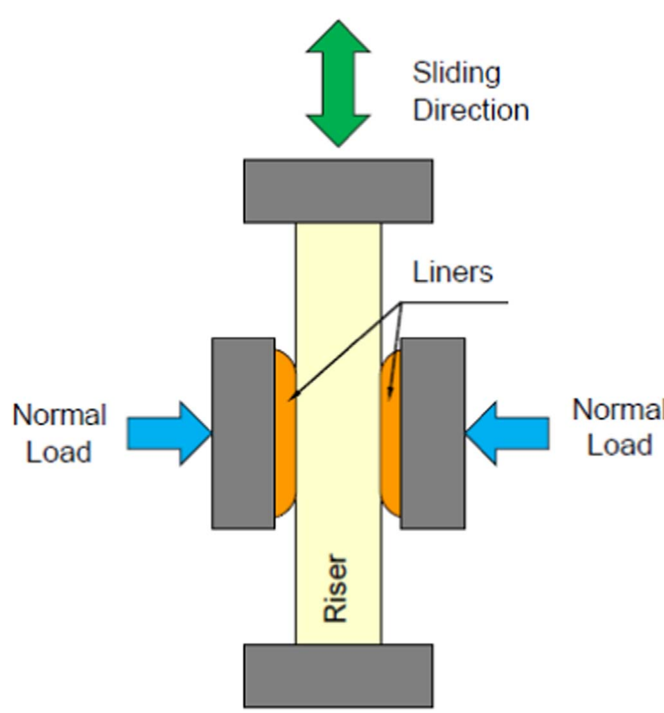

Fig. 1. Schematic representation of the large-scale tribometer to simulate the sliding contact between flexible riser pipes and liners.