

## MARKER LAYER TECHNOLOGY: ADVANCED CRACK DETECTION IN ELASTOMERIC BEARINGS

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### Abstract

Helicopter elastomeric bearings are typically replaced “on condition”, that is, once elastomer fatigue degradation has reached a prescribed depth, the bearings are removed from service. To simplify inspection and enable proactive maintenance, LORD Corporation has developed marker layer technology using a contrasting color elastomer to visually indicate that a bearing is approaching the end of its service life.

### 1. INTRODUCTION

Elastomeric bearings, also known as High Capacity Laminate or HCL bearings, are used in helicopter rotor applications to accommodate loads and motions. These “laminated” or “compressive load carrying” bearings were invented at LORD Corporation in the 1960’s<sup>[1,2]</sup> (Fig. 1) and commercialized for use as helicopter rotor bearings in the 1970’s<sup>[3,4,5]</sup>.

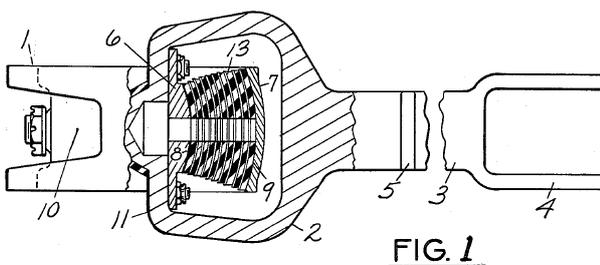
Nov. 19, 1963

J. H. GORNDT ET AL  
ROTOR HEAD

3,111,172

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**FIG. 1**

Figure 1: Early Patent for an Elastomeric Bearing

The bearings consist of thin elastomeric layers sandwiched between rigid shims. The elastomer layers allow for shear motions while the shims make the part stiff in compression. Elastomeric bearings are thus able to support extremely high axial compressive loads while accommodating large motions in torsion and cocking directions (Fig. 2).

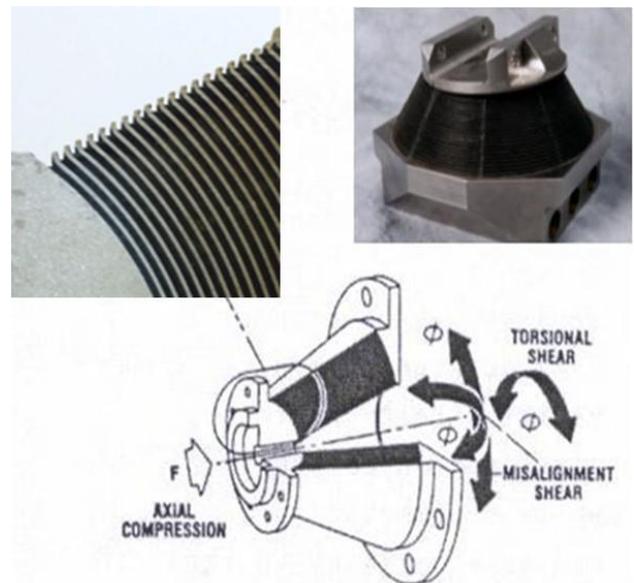


Figure 2: Elastomeric Bearings Accommodate Loads and Motions

Fatigue degradation in HCL bearings normally begins at the exposed elastomer surface on the outer diameter and progresses into the rubber layers towards the center. These bearings are typically replaced “on condition”, that is, once elastomer fatigue degradation has reached a prescribed depth, a bearing is considered to have reached the end of its useful life. Since the earliest development of elastomeric bearings, determination of the extent of cracking while in service has presented a major challenge. The elastomeric layers are quite thin (typically from 0.5 mm to 2.5 mm), making it quite difficult to measure the depth to which a crack has progressed. For some parts, crack depth is determined by inserting a feeler gage into the crack to measure depth (Fig. 3).



Figure 3: Traditional Crack Depth Inspection Using a Feeler Gage

This measurement method is further complicated because of how the parts are used and where they are located on the aircraft. The bearings in service are loaded in compression and the thin elastomeric layers are often spherical making it difficult to insert a feeler gage. Additionally, the parts are generally located in areas that are difficult to access (Fig. 4 and Fig 5).

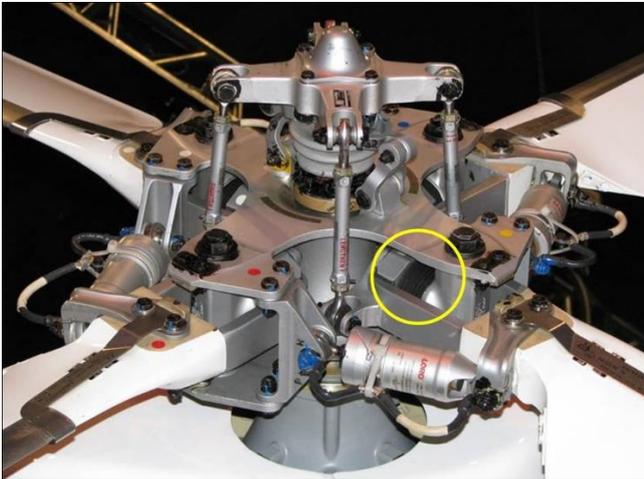


Figure 4: Elastomeric Bearing as Installed on a Helicopter Rotor



Figure 5: Elastomeric Bearing as Installed on a Helicopter Rotor (Inspection via Feeler Gage)

As normal fatigue degradation progresses, particles of the cracked rubber are carried to the surface of the part where they can be visually observed. The high compression loads force the rubber crumbs to the surface where the pressures are lower. These crumbs remain on the surface of the part throughout various helicopter operating conditions (Fig. 6).

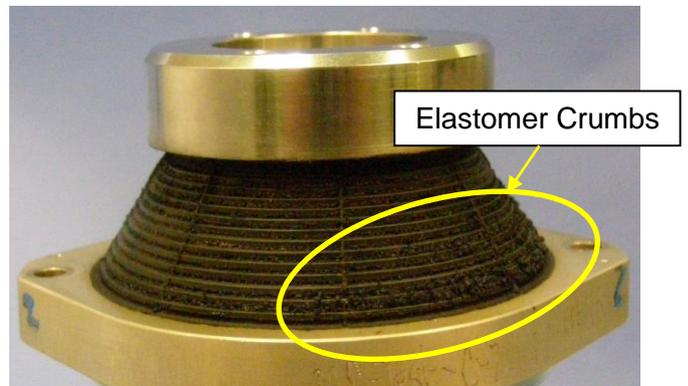


Figure 6: Examples of Crumbs on the Surface of an Elastomeric Bearing Removed from Service

## 2. DISCUSSION

The marker layer technology is a LORD Corporation innovation by which two or more visually distinct elastomers are embedded within the individual layers of an elastomeric bearing. By embedding visually contrasting rubber at predetermined depths, the crack depth in an elastomeric bearing can be monitored by observing the color of the elastomer crumbs as they appear

at the surface. The appearance of contrasting rubber crumbs on the surface from the marker layer is an indication that the bearing is approaching the end of its service life (Fig. 7 and 8). Marker layer provides a proactive maintenance flag so that the removal of the bearing can be scheduled without affecting the flight operations (i.e. 100 hours prior to the bearing removal).

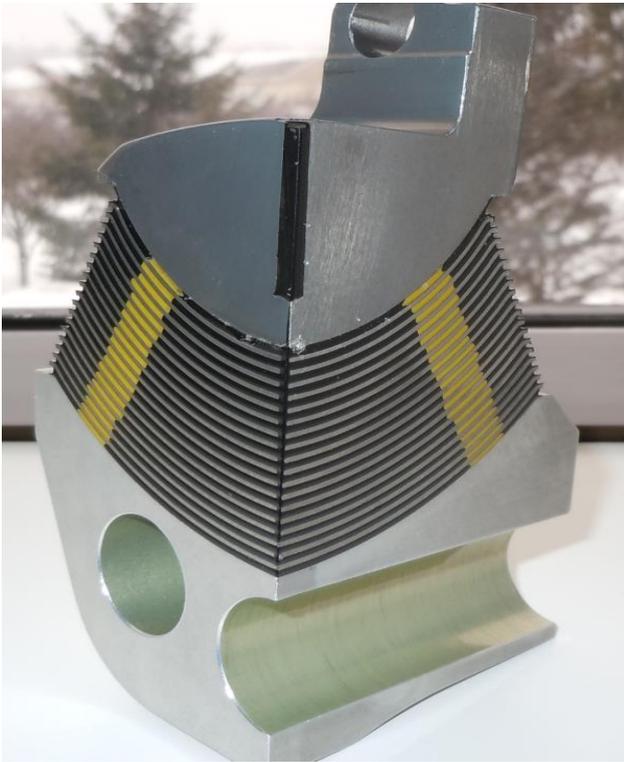


Figure 7: Quarter Section of a Bearing Shows Colored Marker Layer Embedded at a Predetermined Depth



Figure 8: Example of Colored Crumbing at the Surface

While the idea of a marker layer seems simple in theory, it is quite complex in practice. A number of different requirements must be met simultaneously. The marker layer compound must be:

1. Equivalent in dynamic elastic and loss moduli to the layer it is embedded in.
2. Formulated in such a way as to be chemically and thermodynamically compatible with the layer it is embedded in and be able to co-cure with the layer it is embedded in.
3. Able to be kept accurately positioned during vulcanization.
4. Equivalent or better in fatigue resistance to the rest of the layer.
5. Visually distinguishable from the bulk elastomer matrix.

Of these 5, matching the fatigue resistance is perhaps one of the most difficult criterion to meet. Carbon black has long been used as the preferred reinforcement in dynamic parts because of the excellent properties it confers, but it is impossible to make in any color except black. The most obvious substitute is high surface area silica, but silica alters the vulcanization chemistry dramatically because of the concentration of hydroxyl groups on the surface<sup>[6]</sup>. These hydroxyl groups make the silica surface more polar and more acidic than that of carbon black. Carbon black is alkaline which accelerates the cure while silica is acidic which retards the cure. To further complicate the problem, silica absorbs some of the curatives on the surface and it reduces the overall state of cure<sup>[7]</sup>.

Initial development and validation of the marker layer compound utilized fracture mechanics. Fracture mechanics deals with crack growth from intrinsic flaws and can be used to characterize the rate at which strain energy is released as a crack grows. This strain energy release rate is termed "tearing energy" (abbreviated as  $G$ ), and it can be used to characterize the behavior of different materials intended for use in dynamic applications. The fracture mechanics based Fatigue Crack Propagation (FCP) test<sup>[8, 9, 10]</sup> which utilizes a "pure shear" test specimen, was used to characterize the crack growth behavior of black and colored rubber compounds. Additional characterization was performed using thin layer fatigue specimen, which was fatigued in shear under high compression loads (Fig. 9).

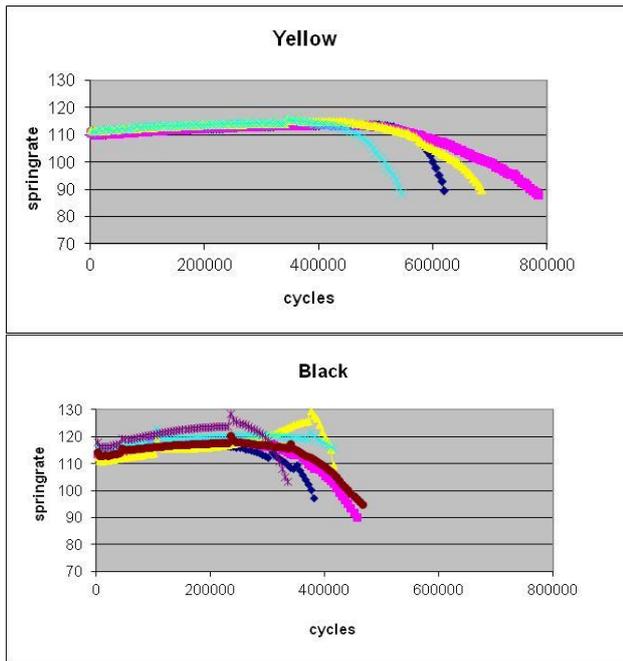


Figure 9: Resistance of Black and Yellow Stocks in Thin Layer Fatigue

Once laboratory data showed that the Marker Layer formulations were as good as or better than the black formulations, parts were made and subjected to fatigue testing. Testing demonstrated that the addition of marker layer materials maintains both the reliability and identical performance characteristics of a standard elastomeric bearing.

Inspection of a bearing containing the marker layer compound is easy. Black crumbs on a black background are difficult to distinguish (Figure 10) and give no indication of crack depth while the yellow crumbs are highly distinguishable against the black background (Fig. 11). Due to the nature of crack propagation in HCL bearings, the elastomer crumbs stay on the surface throughout the helicopter operating environment. The yellow crumbs visible on the surface serve as an inspection enhancement.

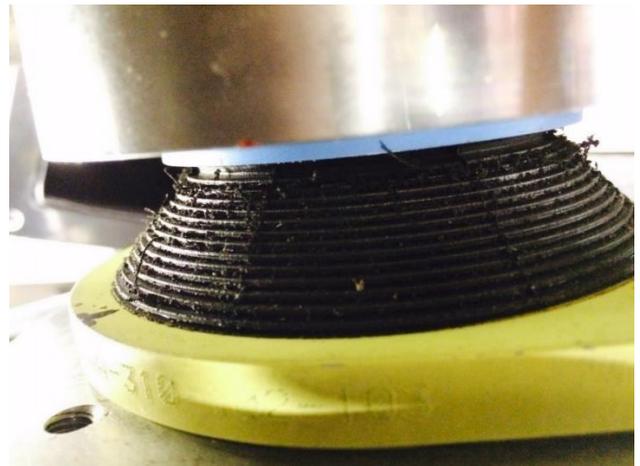


Figure 10: Black Crumbs Provide no Indication of Crack Depth

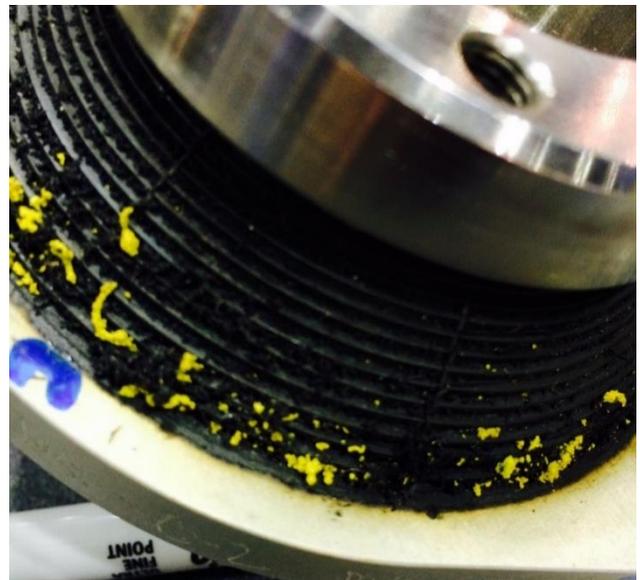


Figure 11: Yellow crumbs are Easily Distinguishable

Currently, the main focus of this discussion has been on spherical thrust bearings, but other elastomeric parts such as rod-ends and tube-forms, can also be fabricated using the marker layer technology (Fig. 12 and 13).

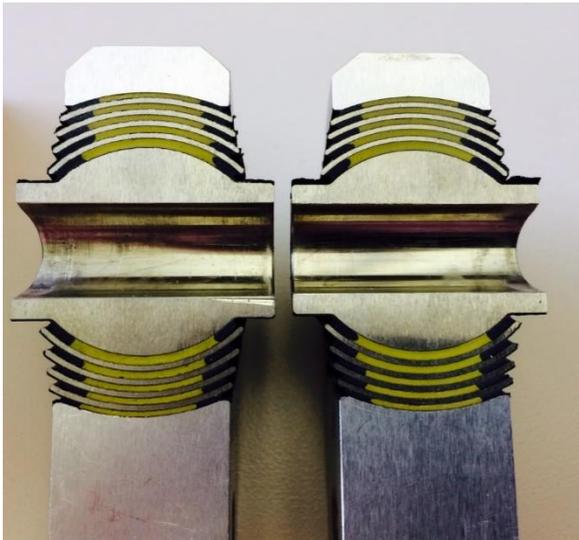


Figure 12: Rod-End Bearing Cross-Section with Embedded Marker Layer



Figure 13: Tube-Form Cross-Section with Embedded Marker Layer

In a survey of sixty (60) maintenance technicians and helicopter operators, the question was asked, “Do you see this technology as a benefit to preflight and post-flight inspection processes?” Ninety-three percent responded with “Yes” (Fig. 14).

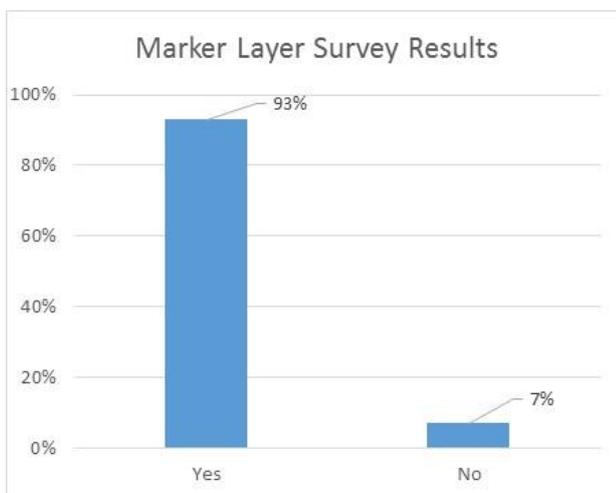


Figure 14: Marker Layer Survey Results

### 3. SUMMARY AND CONCLUSIONS

Elastomeric bearings have been in use on helicopters since the 1970's. These elastomeric bearings are typically replaced “on condition”, that is, once elastomer fatigue degradation has reached a prescribed depth, the bearings are removed from service. Inspection of the depth of cracking has always been difficult to measure accurately. To simplify inspection and enable proactive maintenance, LORD has developed marker layer technology using a yellow colored elastomer embedded at a predetermined depth within the black rubber in the bearing. Crumbs of the yellow elastomer appearing at the surface give a visual indication that a bearing is approaching the end of its service life. Marker layer technology is being certified in various rotary wing applications.

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