A Proposal of Prognostic Inspection and Proactive Maintenance Program for Rolling Bearings

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1. Introduction

Remanufacturing of rolling bearings is well-known methodology not only for saving materials and energy but also saving down time of production in aircraft operation, steel mill operation, train operation, etc. Periodic inspection, maintenance and remanufacturing are common practices and the detail practice for aircraft bearings and train bearings were developed as a standard manual [1, 2].

Built-up fatigue stress in terms of rolling contact fatigue stress and rotary bending fatigue stress could be restored by UNSM (Ultrasonic Surface Modification) and even enhanced them than the original strength fatigue [3]. Application results in steel mill operation showed very good compromise to research results of test specimens [4].

Hence, we'd like to adapt these results to standard remanufacturing manual and propose new concepts **"**Prognostic Inspection and Proactive Maintenance Program for Rolling Bearings" which could bring more saving of materials, energy and downtime of production than those of remanufacturing process. Even the failure rate could be lowered**.**

2. Brief summary of UNSM effects on restoration and enhancement of remanufacturing bearings

2.1. Ultrasonic Nanocrystal Surface Modification (UNSM)

The UNSM is a kind of surface modification methodology like as laser peeing, water jet/cavitation peening, etc. UNSM inputs to the workpiece surface up to 30 Giga Pascal with up to 10 million strikes per cm^2 and up to 2.4 million strikes per minutes. These super dense and high cycle pressure induce severe plastic deformation on top surface, elastoplastic deformation on the next surface, and elastic deformation on the beneath surface. These deformations modify microstructure and mechanical properties very much as shown in Table 1. The performance improvement in terms of fatigue strength, wear resistance, rolling contact fatigue strength, etc. due to these modified structure and properties are also shown in Table 1.

Table 1 Changes by UNSM

Effect of UNSM	Performance Improvement
Deep compressive residual stresses (Greater than 1000MPa into depths of more than 2000 *μm*)	1. LCF, HCF, VHCF Strength 2. Rolling Contact Fatigue Strength 3. Stress Corrosion Cracking Resistance 4. Friction Loss 5. Wear Rate 6. Corrosion Resistance 7. Corrosion Fatigue Strength
Micro dimples surface and improved surface roughness (Dia. Of area 1-2 μm^2 Depth: sub-micron, nanoscale roughness)	
Increase harness(into depths of more than 1500 *μm*)	
Nanocrystal structure (Grain size of 50-200 nm into depths of 200 *μm*)	

2.2. Restoration and enhancement of test specimens and rolling bearing by UNSM

The rolling contact fatigue strength (RCF) of test specimens was restored and enhanced as shown in Table 2. Average service life of new test specimens was 4.61×10^6 cycles at 4.6 Giga Pascal. UNSM on new test specimens increased the average service life by 1.012×10^7 cycles (118%). After built-up 86% of fatigue cycles, some of these specimens were polished and UNSM treated on the fatigue built-up area and continue same RCF test. The remaining service life was 8.32×10^6. This meant that UNSM restored and enhanced the service life more than 1.8 times of new test specimens [3].

The rotary bending fatigue strength (RBF) of test specimens was restored and enhanced as shown in Figure 1. Average service life of new test specimens was 6.4×10^6 cycles at 0.98 Giga Pascal. Two kinds of fatigue cycles built-up were prepared. The first group were 50% of fatigue cycles, the second group were 75% of fatigue cycles. The necks are of two group were treated by UNSM and continued RBF test under same stress level. The remaining fatigue cycles of three group were more than 2.2×10^7, which meant the UNSM restored and enhanced the fatigue strength more than that of new specimens [3].

Restoration and enhancement of RCF in spent spherical rolling bearings and spent rolling bearing

in steel mill operation were carried out. Spent spherical rolling bearing was restored by UNSM and showed 7% improvement of service cycles as shown Table 3 [4]. There were 48 with more than 5 different kinds of heavy and big size spent roller bearings were restored by UNSM treatment as shown in Table 4 and are running in steel mill since 2014. There is no bearing yet showing shorter service life than new bearings.

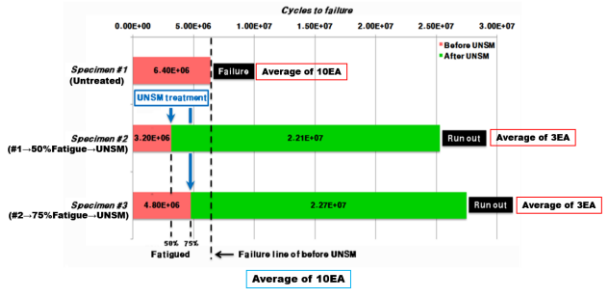

Fig. 1 Result of RBF Test of the SUJ2 specimens

Table 2 Result of Rolling Contact Fatigue Test

Specimen type	Cycle to failure	Ratio [%]
New	4.641×10^6	100.0
UNSM-treated after 86% built-up fatigue cycles	8.323×10^6	179.3

Table 3. Result of Fatigue Life Test Results of Spherical Roller Bearings

Specimen type	Cycles to failure	Ratio [%]
New	6.454×10^5	100.0
UNSM-treated on Spent Bearing	6.915×10^5	107.1

Table 4. In-Field Operation Lists of Steel Mill Bearings after UNSM Remanufacturing

Type of Bearing	
24020-S-MB-C4	390KH5101EGS5+KCG-01
d415.925XD590.55X209.55w	EE755281DWY.360.361D_F
558KV	

3. A Proposal of Prognostic Inspection and Proactive Maintenance Program for Rolling Bearings

A flow chart showing main concepts of prognostic inspection and proactive maintenance program is as shown in Figure 2. The prognostic inspection properties of rolling bearings could be following three items. The first one is surface integrity of race ways, and the second one is surface hardness and the last one is residual stress. The inspection period should be shorter than existing periodic inspection period and 75% of L_{10} service cycles. [5].

The surface integrity could be inspected by visual test and surface roughness test. If there are any kinds of scratch or flake are shown or the surface roughness are bigger than the new one in certain level, it means that remanufacturing and UNSM process should be carried out. The drop criteria of hardness and relieved residual stress are under development. The remanufacturing process is same as aircraft bearing or train wheel bearings. The clearance value should be modified according to the requirement of the system. After UNSM treatment following remanufacturing process, the three prognostic inspection criteria should be validated once more and the remaining service life in L_{10} should be suggested. The detail of flow chart and standard manual should be also developed.

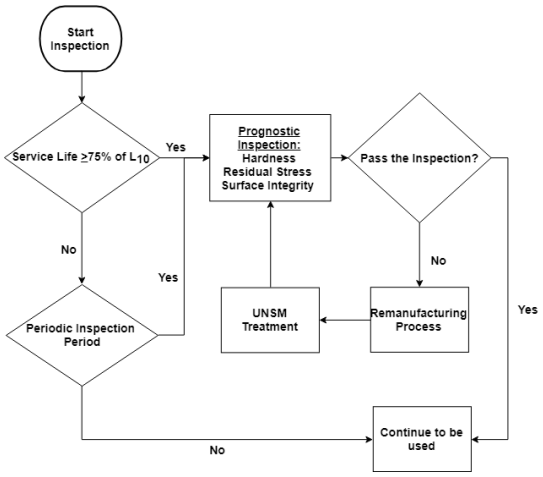

Fig. 2 Flow chart of Proactive Maintenance

4. Concluding remarks

A new concept **"**Prognostic Inspection and Proactive Maintenance Program for Rolling Bearings" which could bring more saving of materials, energy and downtime of production than those of remanufacturing process is proposed. This is just the first step of beginning and lot of collaborative work in academy and industry are needed to build up a standard process.

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