Online Wear Measurements in Advanced Lubricated Systems*)

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1 Introduction

The RTM - Radionuclide Technique in Mechanical engineering – developed continuously and systematically in Karlsruhe is a high precision technique [1–5] for wear and corrosion diagnostics in mechanical and process engineering. This nondestructive online measurement technique is widely used for research and development work of the industries in Europe, North America and Japan [6,7]. The application of new industrial materials (synthetic materials, ceramics, hard coatings etc.) and the worldwide problems in medicine technique (prosthetics) demand further development of RTM, especially the labelling of critical surfaces with radionuclides.

2 RTM – the Radionuclide Technique for Online Wear Diagnosis

The irradiation at the cyclotron accelerator with Thin Layer Activation Technique, TLA, produces an accurate, thin radioactive layer on the surface of the critical machine component. The activation parameter must be selected in such a way that the generated activity versus material depth has a linear dependence, and that the physical and chemical properties of the components are not affected. TLA technique has been developed at Karlsruhe Cyclotron for all industrial iron and steel grades (low-alloy steels up to high-alloy steels), non-ferrous metals and alloys: Al, Co, Cr, Cu, Mo, Ni, Pb, Sn, Ti, V, W, Zn, sintered and hard metals, special ceramics.
As an example of irradiation, Figure 1 demonstrates the adjusting of a large piston ring of a marine diesel engine in front of the beam line of the Karlsruhe cyclotron. The surface over the full circumference has been activated.

The labelled part is remounted in the machine under investigation on a test bench. Two measuring methods are available: TLM and CMM. With TLM, Thin Layer difference Method, the decrease of the radioactive layer during the wear process is measured using a gamma ray detector outside the machine. The wear diagnostics device determines the wear value online on the basis of the calibration ratio of measured activity versus material depth. Precondition of correct function is the transport of the wear particles away from its place of origin.
CMM, Concentration Measuring Method, is usually the more sensitive measurement of wear than TLM. But the resolution depends on the volume of the lubricant and on the level of the specific activity of the labelling. The radioactive wear particles in the lubricant are measured

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with a gamma ray detector in the flow chamber of the closed measuring circuit. The wear of the machine part is proportional to the measured activity of the wear particle concentration in the lubricant. Required is a constant specific activity in the activated volume of the component for the reliable allocation of the measured activity value to wear mass. The required levels of radioactivity are considerably lower for CMM than for TLM. Precondition is that the wear particles enter the lubricant circuit and are suspended homogeneously in the lubricant. The method is described in detail in [1,2,5,10].

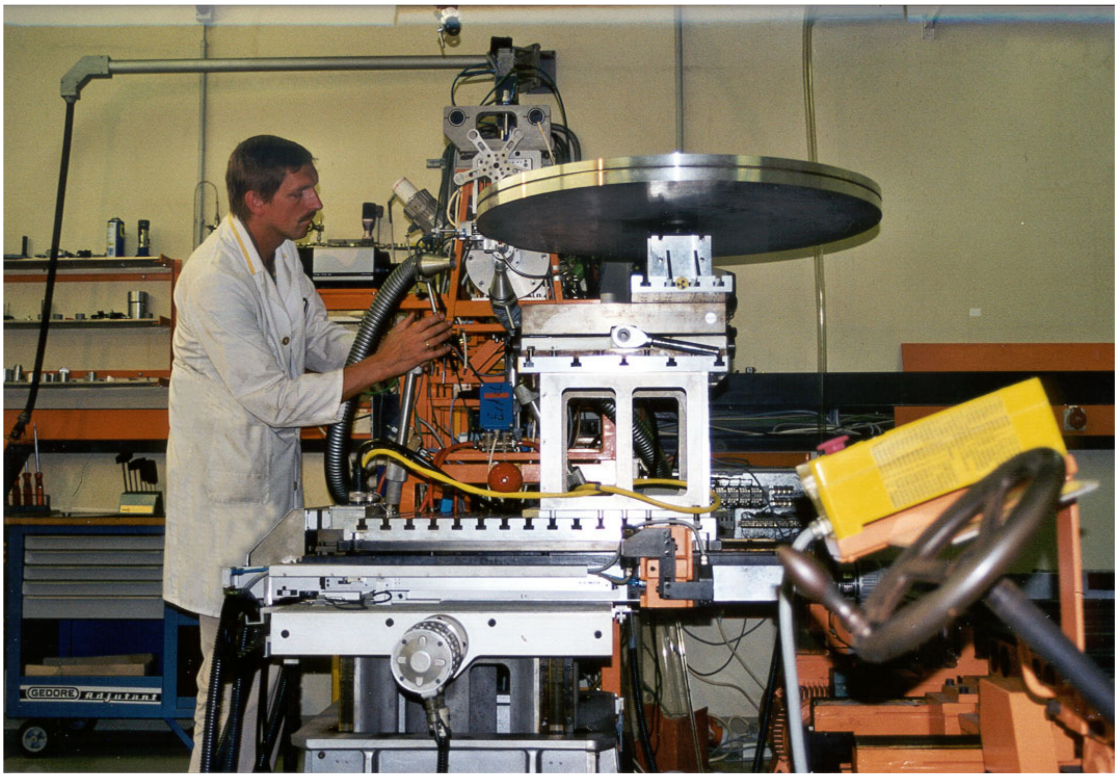

Figure 1: Adjusting of a piston ring of a marine diesel engine in front of the ion beam line in the RTM facility of Karlsruhe cyclotron.

3 Application

RTM is a widely used tool for wear analysis of engine components such as bearings, gears, camshafts, valves, tappets, piston rings, cylinder walls etc. This is the main field of RTM application. But the technique is also used to evaluate corrosion, cavitation and erosion phenomena in pipes, steam and gas turbines, offshore platforms and sea bed pipe work, Chemical and Textile Industry.

RTM has been applied to the development of the first non-C-F-C (Chlorofluorocarbon) refrigerant compressor of production stage. For this purpose a special test bench was developed which has been applied furthermore to larger compressors for air conditioning [4].

Figure 2 demonstrates the result of a wear test with a small piston of a refrigeration compressor labelled in its critical circumference area. The wear of the run-in phase during first hour could be clearly demonstrated because of the high resolution power of 0.2 µg.

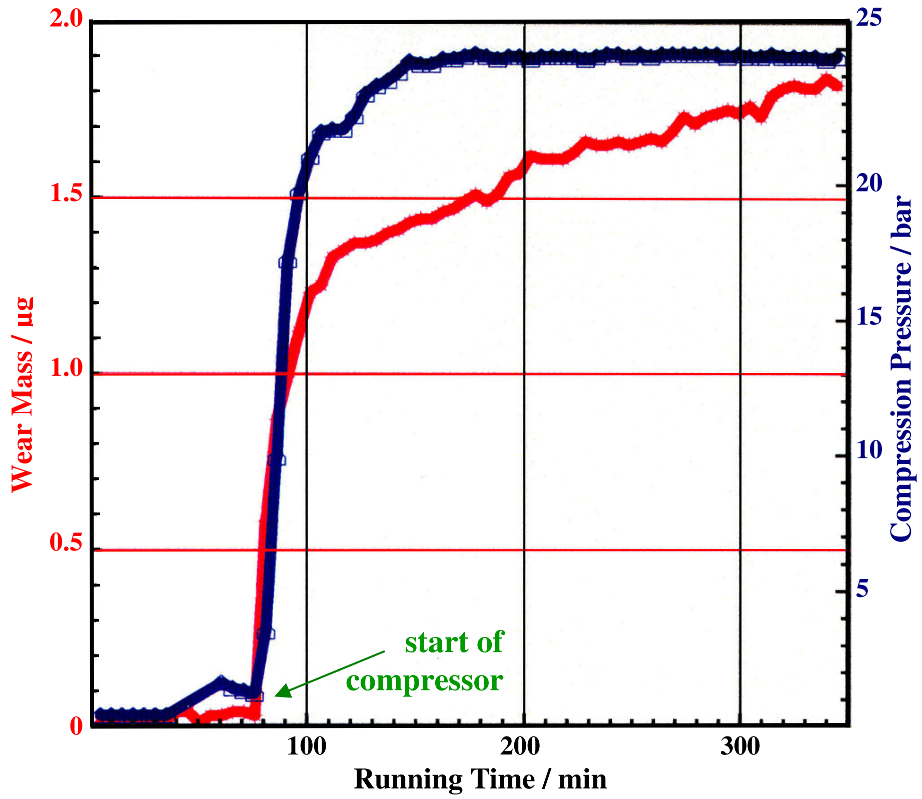

Figure 2: Typical run-in wear of the piston skirt (red curve) of a C-F-C free refrigeration compressor together with its increasing pressure (blue). Activation depth: 15 µm. Detection limit: 0.2 µg, Refrigerant: propane.

RTM has been applied to biomechanical engineering [8]. The number of surgeries for total replacement of bone joints by prostheses increases continuously. One reason is the limited life time of the actual hip joint prostheses which requires a considerable number of revision surgeries. Wear particles are the main reason for the late aseptic slackening of the implants. So a sensitive and reliable measurement of wear is required for the improvement of the life time of prostheses.

A ceramic prosthesis is for a wear measurement technique the most sophisticated friction couple due to the very low wear rates. The conventional standardized simulator test demands long testing periods. Of significant disadvantage is the interruption of the run, the dismantling of the joint for measuring the weight. Each new start produces a new run-in effect. Moreover the usual weight loss measurement is inaccurate because of the hygroscopic properties of the used ceramic material.

We labeled three heads of a ceramic – ceramic hip joint (Al_2O_3). An on-line wear diagnostic system for artificial hip and knee joints was established using the know how of the RTM method (cf. Figure 3). The real time wear measurements of the ceramic prosthesis were performed at a hip joint simulator of the company IMA, Dresden.

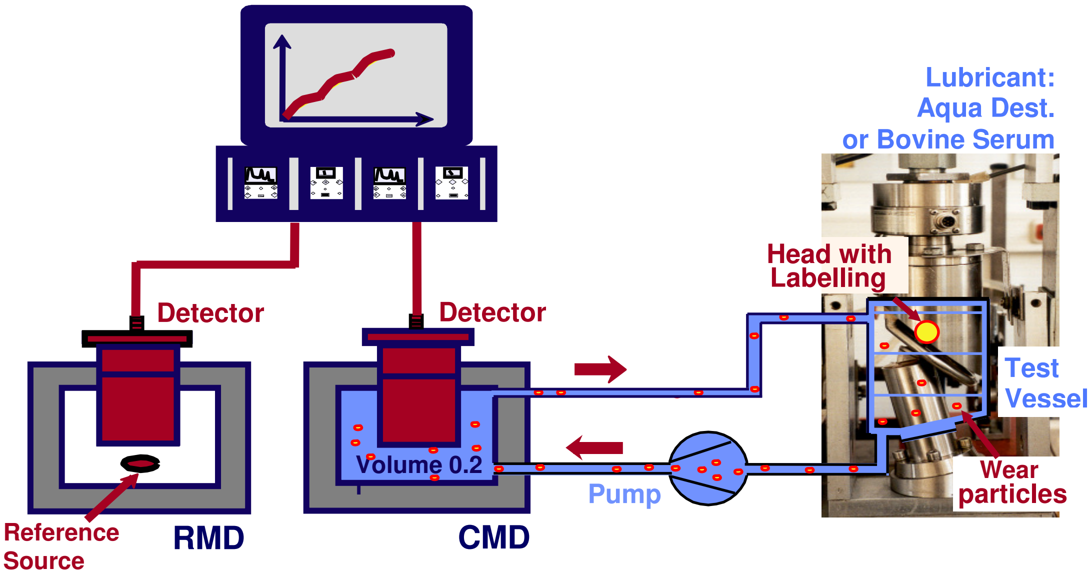

Figure 3: Schematic sketch of the RTM measuring system for prosthetics with Concentration Measuring Device CMD for measuring the activity of the wear particles in the lubricant (calibrated wear mass is displayed online), with Reference Measuring Device RMD for accurate correction of half life and control of correct functioning of the measuring system, and with the hip joint simulator (right) containing the labelled head under investigation. As lubricant were used Aqua dest. and Bovine Serum.

The test results in figure 4 demonstrates the strong run-in wear with an integral wear rate of 40 µg per hour followed by a steady state phase with only 0.3 µg/h. With a higher difference between the lower and the upper load the wear rate increases to 0.5 µg/h.

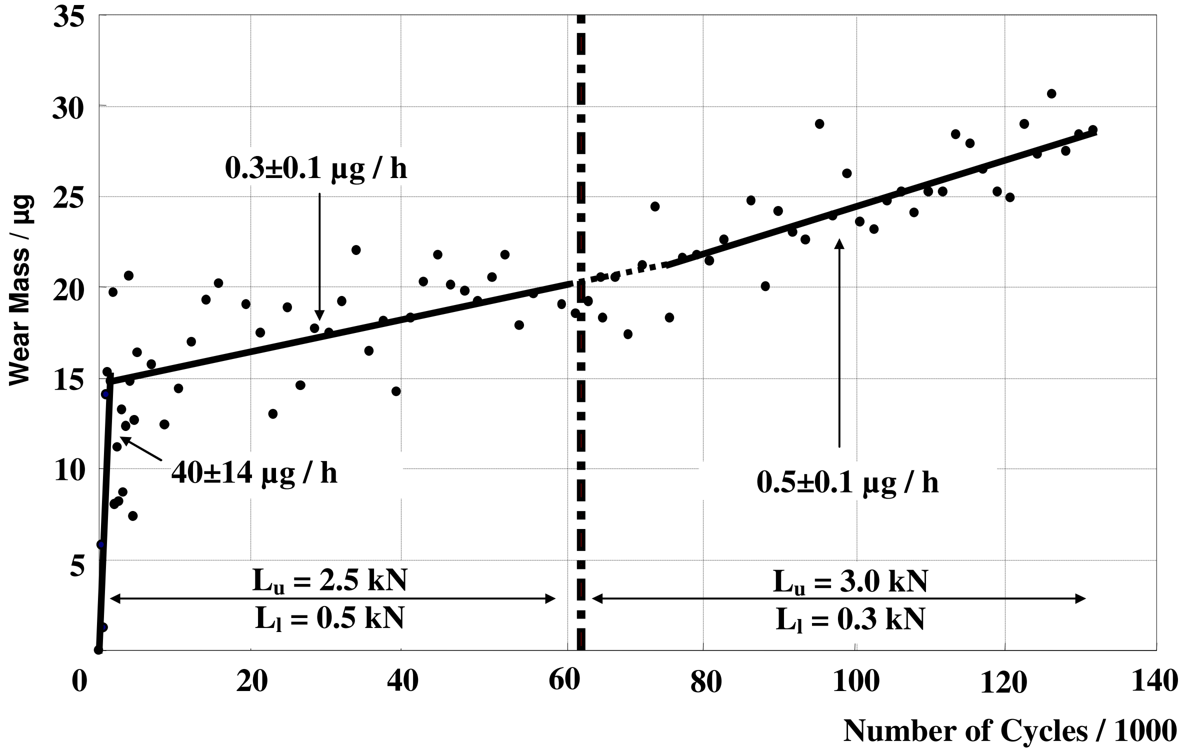

Figure 4: Real time wear measurement of a hip joint prosthesis in a simulator. Material of labelled head and acetabular cup: Al_2O_3; frequency: 1 Hz; 3600 cycles correspond to 1 hour; upper and lower load L_u/L_l in two steps. Raising the load from 2.5/0.5 kN to 3/0.3 kN results an increase of wear rate by 66 %. Remarkable is the high run-in wear rate of 40 µg/h.

3 Developments of RTM

RTM has been developing in Karlsruhe since 50 years. Regarding logistics and radiation protection the beginning in the year 1958 with neutron activation at a nuclear reactor was complicated. The development of RTM measurement and Thin Layer Activation technique, TLA, at Karlsruhe cyclotron in cooperation with RTM customers strongly improved the sensitivity of the method, and the handling of radioactive parts. At this time the application was usually limited to metal components.

The actually running development of Ultra Thin Layer Activation UTLA will allow the labeling of nearly all synthetic and ceramic materials in a depth of some µm [2,3,9]. So the application fields of RTM will become larger. The accuracy will increase and the handling of the radioactive parts will become uncomplicated.

The labeling of DLC coatings has already been established as routine method. The labeling of plastic materials like PTFE and PEEK is in development to a routine method within a cooperation project of ZAG Zyklotron AG and IAVF Antriebstechnik GmbH supported by AiF.

The effect of material damage by radiation was investigated in several activation tests with DLC and PTFE coated engine parts. Microscopic tests, adhesion tests, Raman spectroscopy, X-ray spectroscopy and pin-on-disc tribometer tests have proved that no material damage is generated by the special UTLA.

For test and demonstration purposes a PTFE coated journal bearing (25 x 30 $^{\text{Øi}}$) mm, was radioactive labeled by 7Be implantation to a depth of approx. 5 µm. The applied total activity of 7Be was 10 kBq: that is one thousandth of the free handling limit (10MBq) for this radioactive material. The wear measurements with this labeled bearing were performed on a bearing test bench of IAVF Antriebstechnik GmbH with the concentration measuring method (CMM). The results are illustrated in figure 5 and demonstrate the high sensitivity in the region of 30 nm or 0.01 nm/h. Even in the case of such small wear rates as 0.2 nm/h, the wear step after increasing the surface pressure by 100 % is clearly detectable. At the step of increase of surface pressure a strong decrease of the friction coefficient by 50 % occurs. That is a distinctive feature of this PTFE material.

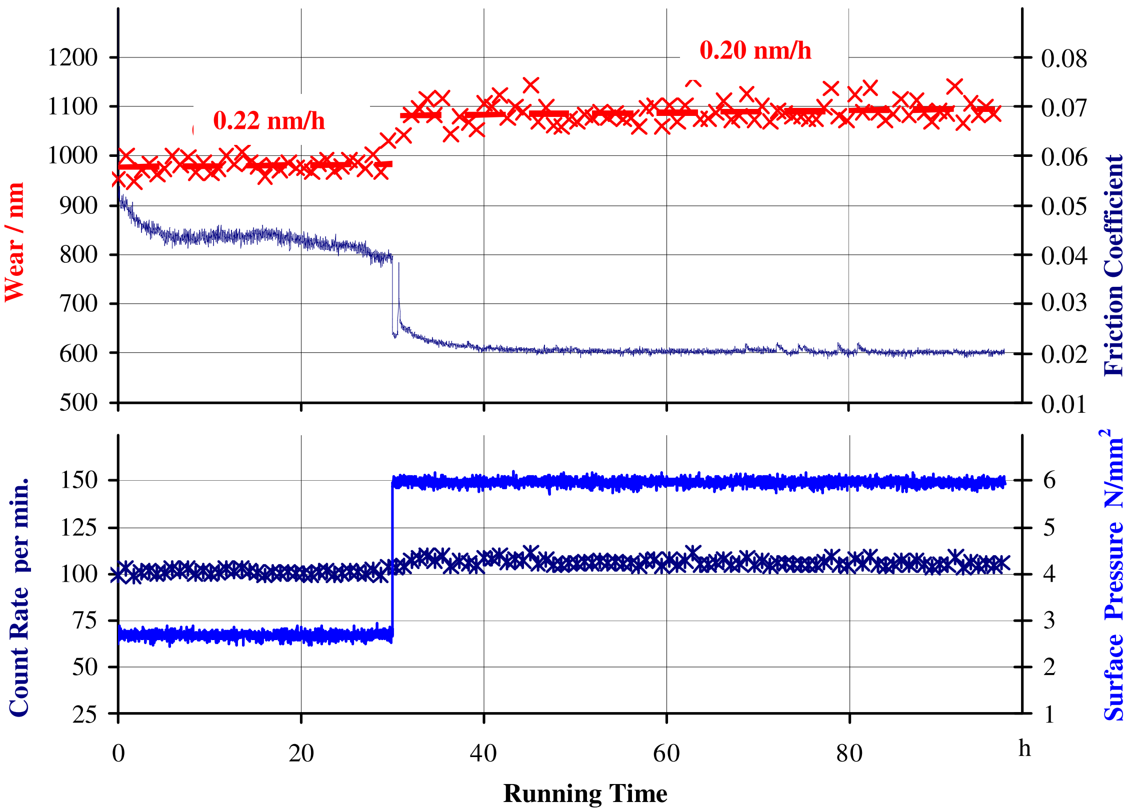

Figure 5: Online measurement of the wear after run-in of a PTFE coated journal bearing on the bearing test bench of IAVF Antriebstechnik GmbH. The PTFE coating (in the range of 7 µm) was labelled with 10 kBq of 7Be to a depth of 5 µm. The count rate in the lower part of the diagram determines the pure output of the radiation detector without calibration, the upper part shows the calibrated result as wear depth. Lubricant: diesel. Sliding speed: 0.5 m/s. The relative standard deviation of wear results is 1.5 %.

The results of a tribometer test (pin-on-disc) with a radioactive labelled DLC coated tappet are presented in figure 6. The test run shows clearly the increase of wear with the stepwise increased surface pressure. At a pressure of 110 N/mm2 a dramatic increase of wear rate from 1 nm/h to 3.3 nm/h was observed in this example of application.

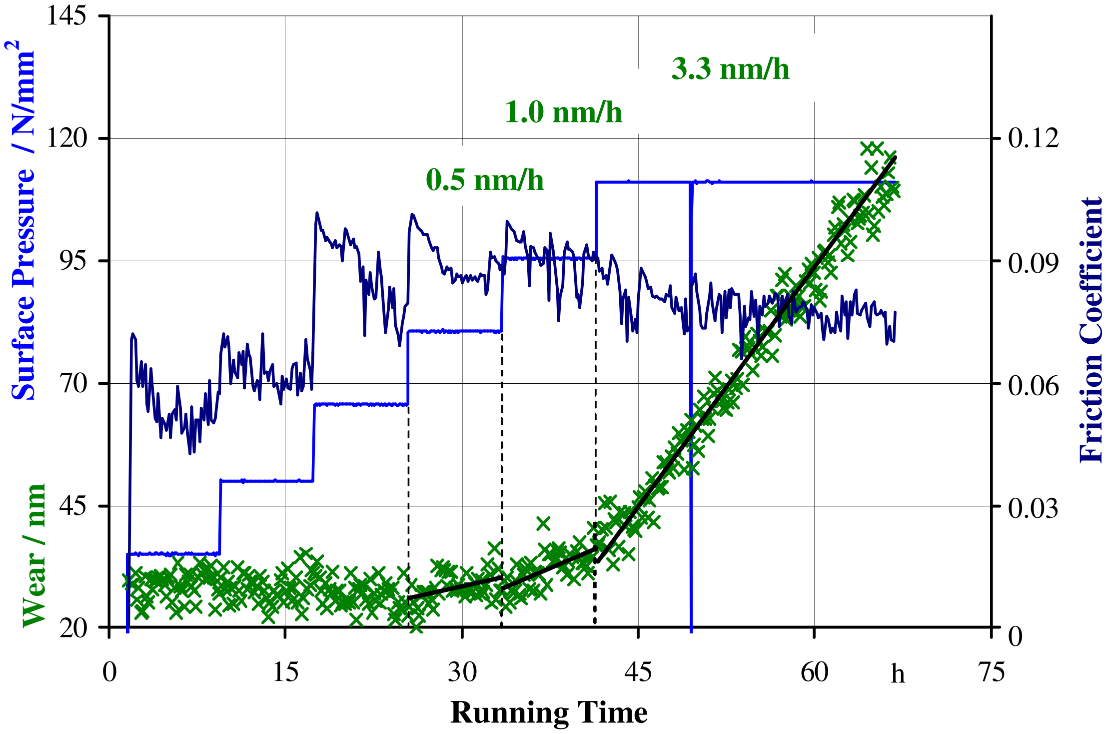

Figure 6: Online measurement of a DLC coated tappet with a pin-on-disc test bench of IAVF Antriebstechnik GmbH. The test results show clearly the increase of wear with the stepwise increased surface pressure. At a pressure of 110 N/mm^2 a dramatic increase of wear rate from 1 nm/h to 3.3 nm/h was observed. Lubricant: engine oil. Temperature of oil: 125 °C. Sliding speed: 3 m/s (high load test). The relative standard deviation of the wear results is 1.3 %.

4 Acknowledgements

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