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# Determination of loads transmitted by rolling elements in a roller bearing using capacitive probes: Finite element validation

Sébastien Murer [a,*], Fabien Bogard [a], Lanto Rasolofondraibe [b], Bernard Pottier [b], Patrick Marconnet [a]

[a] GReSPI, Université de Reims Champagne-Ardenne, Moulin de la Housse, Reims, France
[b] CResTIC, Université de Reims Champagne-Ardenne, Moulin de la Housse, Reims, France

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A B S T R A C T

In this paper, we present the numerical model of an experimental device for measuring the deformation of a bearing ring under radial force. Deflection is measured using a capacitive probe, consisting of a transducer yielding electrical signal from ring deformation. Next, contact force is calculated and linearity of the relationship between load and strain is checked. Thus, we measure the load transmitted by the rolling elements of rolling bearings. A numerical finite element model of the experimental setup is implemented to validate the experimental method and confirm the consistency of the measurement principle.



## 1. Introduction

Mechanical forces generated by moving parts in machines cause vibrations which propagate throughout the structure. During the propagation of vibrations, reflection and refraction phenomena occur due to changes in materials or interfaces between different parts. These considerations justify that vibration sensors are commonly positioned as close as possible to the vibratory source.

Generally, piezoelectric sensors are used: they measure an acceleration; signal quality essentially depends on the position of sensors over the structure. Nevertheless, placement is chosen prior to the machine design, which in addition to the size of these devices makes them hardly ever located at an optimal spot, that is to say where the noise-to-signal ratio of the vibratory information is smaller.

In the vast majority of cases, rotating parts are guided by roller bearings through which the entire vibratory signal of the machine transits.

Therefore, we suggest placing a capacitive probe close to the fixed ring of a bearing in order to intercept almost unaffected vibratory data. Such a kind of displacement sensor translates ring deformation into real-time electrical signals, which has several advantages [1–4] among which the possibility of being integrated from the machine design step due to its small mass and dimensions.

* Corresponding author. Tel.: +33 3 26 91 81 20.
*E-mail address:* sebastien.murer@univ-reims.fr (S. Murer).

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A similar technique called REBAM® [5] uses inductive displacement sensors, whose major drawbacks are the following:

- Sensitivity: 0.1 mm.
- Operating frequency: 10 kHz.
- Difficult to miniaturize.

Capacitive probes have significant advantages over inductive ones:

- Nanometric precision displacement measurement.
- Contact-free measurement (robustness).
- Excellent repeatability.
- Negligible influence of thermal conditions.
- Small size allows easy positioning, no ring machining required.
- Can operate in static and dynamic contexts.
- Wide bandwidth (100 kHz).
- Easily manufactured.

Capacitive probes can also be used for ongoing measures of forces acting on vehicle wheels (e.g. active safety systems) [6].

Finally, capacitive sensors are quite suitable for the measurement of static loads applied to lifting machines and allow retrieving location information under a special sensor arrangement over the bearing.

An experimental bench has been devised to measure static forces transmitted by rolling elements to prove feasibility of this measurement method. Results have been confirmed by FEM simulations. A specific study has been carried out to model the test bench, noticeably featuring connector elements in place of the bearing cage. Numerical values of loads and displacements are compared to experimental results.

## 2. Bearing instrumented with capacitive probes

### 2.1. Displacement measurement of the bearing ring

The use of capacitive probes allows accurate measurement of the bearing ring displacement which is required to access static forces. The stress–strain relationship is linear. Probe is able to measure displacements with an accuracy as small as 20 nm, which is sufficient for the bearing of interest, as well as high reliability [7–9].

### 2.2. Measurement principle

The principle of capacitive measurement of a displacement is based upon the way an ideal planar condenser works [10,11] (see Fig. 1). The quantity being measured is a capacity variation. The sensor and the rolling bearing outer ring represent the electrodes of the capacitor. Capacitance measurement is carried out by injecting a sinusoidal alternating current with constant amplitude and frequency into the probe. The alternating voltage applied to the sensor is proportional

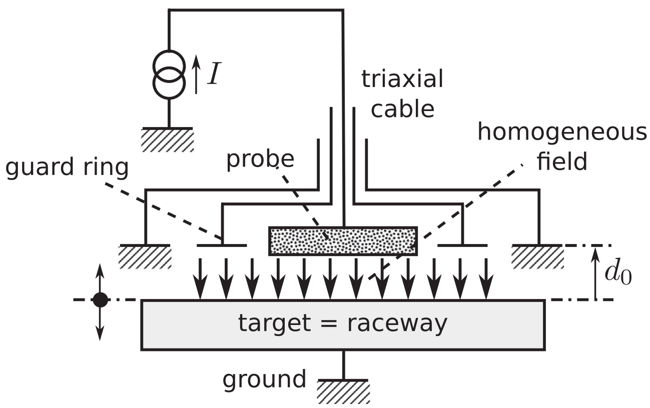


**Fig. 1.** Principle of capacitive measurement.