STUDIES AND RESEARCH ON THE DEVELOPMENT OF A DETECTION SYSTEM BASED ON THE CAPACITIVE EFFECT AND ON THE TECHNIQUES OF SEPARATION OF SOURCES APPLIED ON THE EQUIPMENT IN THE FOOD INDUSTRY, IN ORDER TO ENSURE THE SAFETY OF PEOPLE

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Abstract
This paper presents studies and researches for the realization of a device based on the properties of the electric field and of the variation of capacity, based on the capacitive effect and on techniques of separation of sources, applied on the equipment in the food industry, in order to ensure the safety of people when using the machines. Its main purpose is to detect and locate an operator or object in a protected area. This can be implemented using a mechanical articulated system (robot, press) that estimates the distance between the sensors fixed on such a system and a mobile target. The sensors are made of paint with conductive properties, so they are of reduced size and weight. This sensor has great potential to detect and estimate distant targets. To identify a target: human being or object; and to locate it around a robot, its geometry and physical phenomena related to the target-sensor coupling are essential, as well as the implementation of the sensors.

Keywords: capacitive effect; safety device; capacitive sensor.

INTRODUCTION

In order to ensure the safety of people in the use of equipment in the food industry, an industry that is a priority, new protection systems have been continuously developed. In this paper are presented the security systems implemented on machines used in the food industry with a variable geometry.

In recent years, robots have been increasingly used in production halls. To prevent new risks of accidents, new security equipment and technologies have been developed. However, safety is not completely ensured during protective interventions, and in this case, some protections need to be neutralised. (L. Albera 2003, M.B. Malmiri, 2002)

To this end, a new safety device has been developed, device that is based on the properties of electric field and variable capacity. Its main purpose is to detect and locate an operator or object in a protected area. This can be implemented using a mechanical articulated system (robot, press) that estimates the distance between the sensors fixed on such a system and a mobile target. (L. Albera 2003, B. Pottier et all, 2007)

The sensors are made of paint with conductive properties, so they are of reduced size and weight. The results show that this sensor has great potential to detect and estimate remote targets.

Such a detection principle has been implemented on hazardous machinery for which geometry is well defined and the mode of operation is vital to an appropriate safety threshold. In robotics, geometry is variable, and then capacitive variation of the system must also be taken into account.

To identify a target: human being or object; and to locate it around a robot, its geometry and physical phenomena related to the target-sensor coupling are essential, as well as the implementation of the sensors. (L. Albera 2003, M.B. Malmiri, 2002)

The separation by estimation of the effect of sources has recently attracted significant interest in the field of signal processing. The separation by estimation of the effect of sources finds its place in a large number of applications in different fields (digital, communications, etc.). The principle of separation by estimation of sources is to establish the parameters of the sources emitted solely on the basis of the observations of the sensors and without knowing data on the mixing process, if we considered the sources as statistically independent (L. Albera 2003, M.B. Malmiri, 2002, B. Pottier et all, 2007). In this regard, many algorithms have been developed over the last decade. Some are related to signal correlation (PCA) and others are trying to restore the independence of higher order signals (ICA). The identification of the mixture matrix and the extraction of the source are distinguished, depending on the application. This system for identifying the mixture matrix is of great interest, because it helps to estimate the influence of the capacitive coefficient of the system. The purpose of this work, apart from the installation of an experimental system, is to show that this problem can relate to a case of separation in the blind of sources. (L. Albera 2003, M.B. Malmiri, 2002)

MATERIAL AND METHOD

The capacitive protection system is dedicated to the safety of people working in places with automatic production in the food industry. The system is implemented in a mechanical articulated system (robot, press, etc.). Capacitive sensors use the properties of the electric field to estimate the distance between them and a target. At the same time, it is possible to differentiate by sensors between a human being and an object and to find out information related to distance (L. Albera 2003, B. Pottier et all, 2006). At the same time, it is also taken into account the variations in capacity that the machine induces on its own because of the shape (the interactions between the different components of the mechanical system and the relative proximity of the soil). The sensory components of the detection are cheap because they are made up of conductive paint applied to the dangerous parts of the machine. Their weight and space are negligible, this aspect being essential for the proper functioning of the machine (L. Albera 2003, B. Pottier et all, 2007).

The use of industrial robots in mass production in the food industry has led to new risks. For these newly emerging risks, new security equipment and new methodologies have been developed. However, safety is not complete where during intervention the protective equipment must be neutralised.

Static and dynamic load measurement in rotating segments using integrated capacitive sensors.

In order to measure the static and dynamic load generated by the machine in the rotary motion, a capacitive sensor is integrated into rotating segments. The sensor consists of two capacitive probes that restore the deformations of the rotating segments and turn them into an electrical signal. Due to the fact that they are very close to rotating parts the quality of the signal is very good. The shape of the sensor and its very small need for space allow its implementation during the creation of the machine. There is a wide range of applications of these sensors:

a) mounted on the wheels of motorized vehicles, they allow to improve the quality of the information transmitted to the safety devices;

b) mounted on elevator components, they measure the load;

c) they allow the surveillance of technical defects by vibration analysis.

Supervision of rotary machines

In order to avoid unforeseen and costly production interruptions, companies maintain and supervise the condition of permanently productive machines. The rotating components are greased with standard or special oil and grease depending on the type of component (steel, ceramics, etc.), the environment (humidity, corrosive, etc.) and the application (speed, temperature, etc.). However, supervising the general condition of the machines is very important. In this respect, vibration analysis is the most popular and effective method of detecting future damage. This is based on the analysis of the signals perceived by an electromechanical sensor fixed on the frame of a machine. In general, these sensors, can measure physical sizes like Xi distancing, Vi speed and gi acceleration. (L. Albera 2003, M.B. Malmiri, 2002)

During rotational movements, bearings are in great demand. Every time a bearing strikes, that periodic shock generates a small signature that is included in the overall vibration signal. The size of the shock depends on the size of the defect. Defects of the sprockets, affect the signal components (time or frequency), and their detection is quite difficult. A mixture of signals is formed (one signal from each vibrating part of the machine) and some of the information is lost depending on the distance between the defect and the sensor. (J-P Pérez et all, 2002, B. Pottier et all, 2006, A. Belouchrani, M. G. Amin, 1998)

In order to improve the quality of the signal received, the location of the sensor must be optimised in order to choose it as close as possible to the mobile components. The main idea is their positioning inside the rotating components, thus being located between the fixed and mobile components of the machine. Each sensor consists of a coupling of two capacitive probes with variable distance. At each moment, the distance between the probes depends on the perceived vibration allowing the measurement of the Xi distance. (T. Kobayashi, 2000,)

With the help of this device, it is also possible to measure:

(a) distortions caused by the wheels of motorised vehicles; from the direct measurement, the request is made in pneumatic contacts and can be intervened in real time at the integrated safety devices;

(T. Kobayashi, 2000, A. Belouchrani, M. G. Amin, 1998)

b) static demand of industrial machinery bearings (mobile bridges, etc.).

Capacitive probe

A. Hertz pressure and the operational principle of the sensor

1) Hertz Pressure:

The contact between the rotating component and the ring of the drum is shaped as a contact line. The pressure distributed may be:

a) uniform along this line, has the form of half an ellipse;

b) point in the direction of width (Fig.1). In practice, the rotating cylinder compensates for the load, and thus the contact line of the drum is less than its length.

The Hertz pressure corresponds to a maximum P0 value allowed on the large axis of the semi-ellipse. At higher values, the material can be destroyed. The working pressure must not exceed the pressure borne by the material. For drum bearings, manufacturers use the P0 p_{permis} value, with p_{permis}=4GPa. (L. Albera 2003, J-P Pérez et all, 2002, J.F. Cardoso, 1998)

When the load is evenly distributed over the half of the drum, the deformations and stresses suffered by the solid bodies in contact shall be expressed analytically, depending on the contact pressure and the contact surface. We consider it a Cartesian coordinate system. Fig. 2 shows us the variation of deformations (z) on the contact area. The normal σ_{zz} strain decreases rapidly by z, while the lateral stresses σ_{xx} and σ_{yy} on the x and y directions increase at first, then decrease along the z. This different behavior gives rise to a tangential τ_{ij} request that prevents the destruction of the segment. The most demanded area is between 0.48b and 0.78b where b is half the width of the contact (Figure 2).

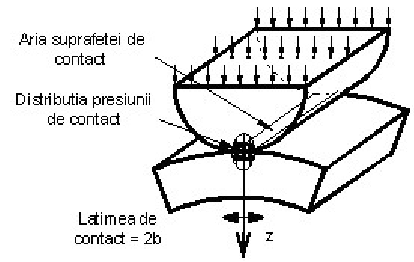

Figure 1. The line of contact between the rotary component and the ring of the drum.

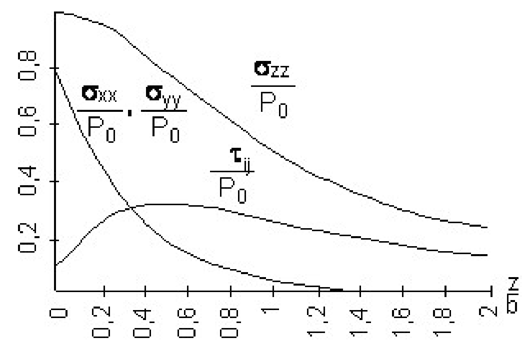

Figure. 2. Deformation variation (z) by contact area

Operational principle of the sensor

Inside the ring, similar deformations are related to the request by a rigidity matrix. These, decrease with the depth z according to Hooke's law in linear elasticity:

$$\varepsilon_z = \frac{1}{E}\left[\sigma_z - \upsilon\left(\sigma_x + \sigma_y\right)\right] \quad (1)$$

where:

ε_z is the unitary elongation of z;

ν: Poisson coefficient of the material;

E: Young Module of Longitudinal Elasticity; (T. Kobayashi, 2000, J-P Pérez et all, 2002)

σ_i: the component of the request on the i direction.

The slope of the deformation in the thickness of a ring is perpendicular to the contact surface of the solids (Fig. 3). The ring was engaged with n finite elements according to its thickness. We consider two points X1 close to the contact surface of the ring and Xn in the thickness of the ring (Figure 3). Their differential displacement ΔD is calculated as follows:

$$\Delta D = \sum_{i=1}^{n} \Delta X_i \quad (2)$$

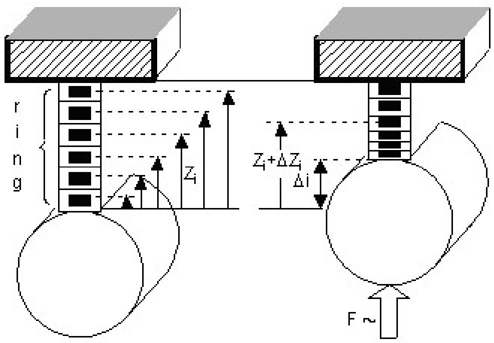

Figure 3. Slope of deformation inside the rotating ring

Features of the capacitive probe

In the proposed layout drawn in Figure 4, the capacitive probes are placed inside the ring. The bearing ability is not affected and the concentration of stress increases by 20%. (T. Kobayashi, 2000, Andrzej Cichocki, Shun-Ichi Amari, 2002)

The ring was drilled, the hole having a diameter of 0.5 mm. The bottom hole is located 1.2 b from the surface of contact with the drum. Thus, this distance avoids the beginning place of the cracks. A path was made on the ring.

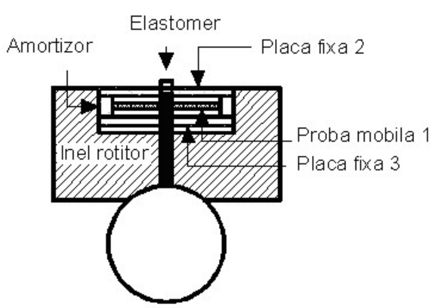

Figure 4. Diagram of the capacitive probe

The deformation of the path is not flat and in order to manage a flat capacitor, each plate consists of a stripe covered with a silver conductor (Figure 5). These stripes are rigidly attached to the walls of the path. The probe is rigidly attached to a steel lever. One end of the steel lever is permanently kept in contact with the bottom of the path by an elastomer placed at the other end (Figure 4, Figure 5) (L. Albera 2003, Andrzej Cichocki, Shun-Ichi Amari, 2002). Two shock absorbers are fixed to the walls to keep the mechanical strip of the probe at frequencies that go. The movable plate 1 moves in its normal direction, and the other two plates are rigidly fixed. Thus three identical plates are on the ring (Figure 6) (T. Kobayashi, 2000, Andrzej Cichocki, Shun-Ichi Amari, 2002). They play the role of the capacitive probe and can detect the place of maximum stress.

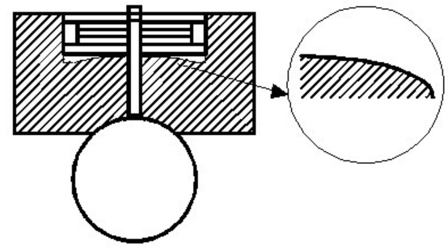
Figure 5. Deformation at the base of the path.

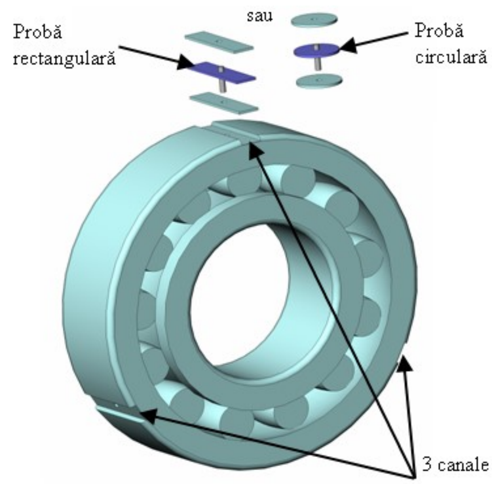

Figure 6. Probe implantation sites on a rotating ring.

RESULTS AND DISCUSSIONS

Simulation of the capacitive protection system for robots. Figure 7 shows the schematic implementation of circuits.

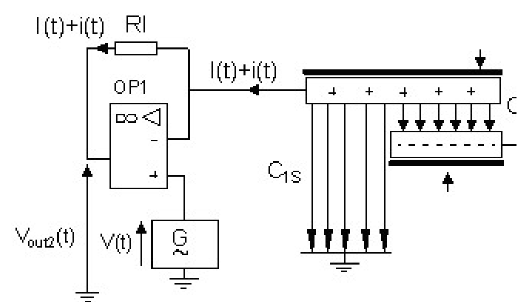

Figure7. Implementation scheme of capacitive coupling translation

Two Voltages Vs1 and Vs2 are available (T. Kobayashi, 2000, P. Comon, 1999). They translate the evolution of the capacity of each sensor according to the distance d between them. Its value decreases when the electric field waves encounter a target. From the equations (4.20) and (4.21), C11 and C12 become:

$$C_{11} = C_{1s}(d) + C_{21} = \frac{1}{V_e R \omega}\sqrt{V_{s1}^2 - V_e^2} \qquad (3)$$

$$C_{12} = C_{21} = \frac{1}{V_e R\omega} V_{s2} \qquad (4)$$

The difference between the two, leads to an experimental model as follows:

$$C_{1s}(d)_{exp} = C_{11} - C_{21} = \frac{1}{V_e R\omega}\left(\sqrt{V_{s1}^2 - V_e^2} - V_{s2}\right) \qquad (5)$$

At the same time, an intuitive reference model was built from the reflection of the couplings. It fits the experimental model by adjusting with a parameter β:

$$C_{1s}(d)_{mod} = C_{1s\infty}\left[1 - \frac{C_{21}^{\alpha}}{C_{1s\infty} + C_{21}}\right] \qquad (6)$$

$$\alpha = \frac{C_{1s\infty} + \beta C_{21}}{C_{1s\infty}} \qquad (7)$$

Different types of intrusions have been tested; the man and the metal target. The output voltages have been measured, Cintrus/i(d), Cintrus/i(d+Δd) have been calculated according to equation (6) and are shown in Figure 8. (T. Kobayashi, 2000, P. Comon, 1999)

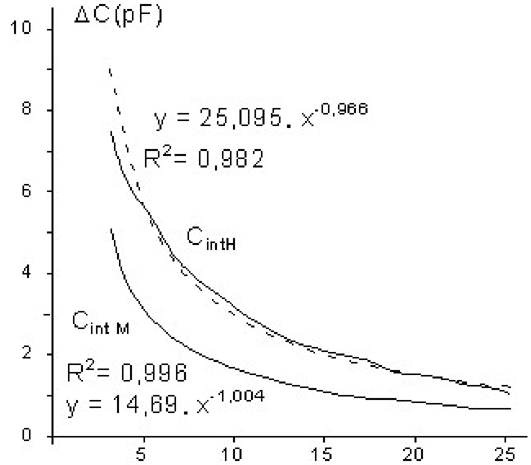

Figure 8. Experimental results, sensor-intruder coupling depending on distance d: CintrusO for humans and CintrusM for metal target

Table 1

Human intruder (*Δd=5mm*)

d	*C_{intrusO}*	*C_{intrusO} (d+Δd)*	*θ_O*	*d_O*
4	6,1	5,422	1,36	4,50
6	4,5	4,154	0,69	6,50
8	3,6	3,388	0,42	8,50
10	2,943	2,803	0,28	10,50
12	2,456	2,358	0,20	12,50
14	2,0442	1,974	0,14	14,50
16	1,84	1,784	0,11	16,50
18	1,5406	1,499	0,08	18,50
20	1,3609	1,328	0,07	20,50
22	1,2031	1,176	0,05	22,50
24	1,01	0,989	0,04	24,50
25	0,956	0,937	0,04	25,50

When the intruder is mobile, (ε.S) fluctuates around the value measured when it is immobile. For a human 0.85(ε.S)O<(ε. S)O<1,15(ε.S)O. From the equation (6.11), by successively changing the role of the active sensor, the capacitive couplings between the intruder and the active sensors are measurable. These measurements, the triangle method and the knowledge of the articulation variables of the robot, make it possible to locate and differentiate the intruder.

CONCLUSIONS

The innovative and inexpensive sensory device has been built and tested to estimate the distance between sensors and an intruder. An interdigital configuration was manufactured which, after testing, can be said to be able to differentiate man from metal objects. At the same time, it also takes into account the variations in capacity that the machine induces on its own because of the shape. This inexpensive system can be implemented to improve safety in factories with robotic production.

The capacitive protection system is based on the measurement of the influence of the capacitive coefficient. The different parts of the variable geometry machine are equipped with sensors, each emitting an electric field of different frequencies (several kilohertz). These sensors also act with the receptors, detecting different mixtures of electric fields.

We have shown that there is an influence of one given sensor on another. These influences are dependent on the distance between the sensors. We have shown, through a system with two sensors, that the influences are almost identical. We have also shown that this system is equivalent to a linear system. The influences observed in each sensor can be used to separate useful information and identify the mixture matrix, collecting information about the influence coefficients. As far as possible, we tried to avoid other influences and to signal the detection of an intrusion. The classic separation algorithms of the sources helped me, having satisfactory results; the signals being practically stationary.

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