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PRESSURE SENSING VIA OPTICAL INETRFEROMETRIC PRINCIPLE

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Abstract: This paper describes steps involved in a new type of pressure sensing. Significance of this approach and propose approaches for improving sensitivity, resistance to electromagnetic interference, dimensions and accuracy. The goal of the project is the research of complex smart pressure sensor based on the new sensing system with galvanic fiber optic isolation including research and experimental validation of this new pressure sensing principle.

The objectives of the project of applied research are in new methods and technology of pressure sensors with galvanic isolation and function specimen of smart optical pressure sensor for explosive industrial environment and/or environment with high electromagnetic interference and very high precision and absolute resistance to electric and magnetic interference.

Keywords: pressure, optic, sensor.

1. INTRODUCTION

Pressure sensor presents key technology for safety operating of different technical products, systems and technologies. They are founding wide recovery in medicine and in different experimental and developmental process and in diagnostic process etc. New presented trend is designing of so-called intelligent pressure sensor. Intelligent pressure sensors are composed of the electronic circuits and the passive parts, which are determined e.g. for linearization of sensor's characteristics and decreasing its dependence on temperature and setting of measuring range, zero point etc. The most powerful pressure sensor contains microelectronic circuits, which enable to install the digital pressure gauge just in sensor and software-control starting of different electronic regulation (warning signal etc.) in according to the measured value. Special pressure sensors present sensors for explosive environment. Pressure is measured in a very wide range from 10^{-12} Pa for extreme vacuum until 10^{12} Pa at research pressure in explosion. In the widest class of pressure sensors there is used exactly defined deformation member, whose deviation or more precisely deformation is linearly adequate of applied pressure. This mechanical value is converted into an electrical digital signal. Used electric conversion method determines metrological and technical characteristic of the pressure sensor.

Contemporary principles for transmission of mechanical changes to the deformation member on the electric signal are piezoresistent principle, inductive principle, capacitive principle, piezoelectric principle, thermo-electrical principle, acoustic principle.

All of these principles have a large number of technological limitations, which defend a complex using of the pressure sensor in explosive environment.

2. PURPOSE

Main goal of this project was to develop a new unique method for scanning deflection of deformation membrane and applying it in practical applications. The new method is based on the optical measuring system with optical fibers. Main advantages of this principle consists in excellent pressure sensitivity, galvanic isolating of whole sensor via optical fiber, very good accuracy of static and dynamic measuring, maximum immunity against electrical and magnetic interference and miniature size of resulting pressure sensor. Those attributes of pressure sensor based on optical sensing principle are optimal for using in explosive gas environment and in environment with high electromagnetic interference.

This new pressure sensor opens new possibilities for application in very special cases in e.g. military or security applications without danger of electromagnetic tapping.

3. METHODS

There are a lot of physical principles for optical sensing. The main used sensor type for optical scanning are:

- amplitude-optical beam sensor,
- phase-optical beam sensor,
- polarization-optical beam sensor,
- Frequency-optical beam sensor.

For our new optical sensor we decided to use amplitude-optical physical principle for good range to linearity ratio, small construction and simple receiving logic. We tested several method of sensing and several structures. The main problem of this solution was creating lens or fiber ending under defined angle and small accuracy of this sensor. From those manufacture problems results several problems with sensitivity and linearity. For improving of sensitivity we used a very simple trick with nonlinear mask which was created on the end of transmitting fiber.

4. RESULTS

This section introduces concepts and the related work on ... telligent pressure sensor. An intelligent ... a device that comprises in a compact small ... re sens... d ASIC (Applic... n Specific Inte... t) for signal conditioning, calibration, ... mmunication.

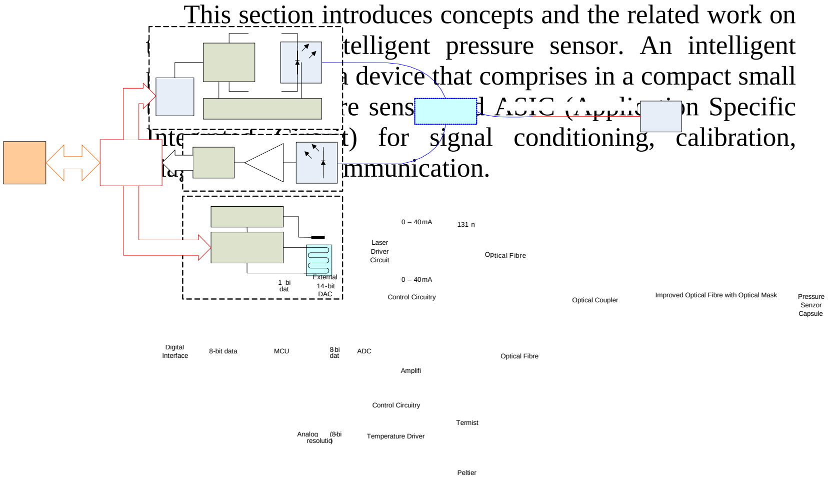
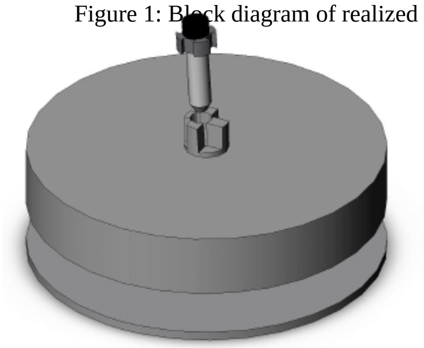


Figure 1: Block diagram of realized prototype of pressure sensor



... is created from optical ... e, optical connector and ... SIC module.

Figure 2: Schematic 3D view of pressure sensor capsule

For determination of the best reflective membrane material we measured several conventional materials for membranes (stainless, beck, hastelloy etc.). Ideal membrane material from optical point of view is tantalum. It has only 2,88% error variance with high usable range on linear part of measured characteristic. Total range of deformation is 50 nm. For computation of membrane dimensions we analyzed material properties and make up common equations. On the basis of these equations was created software tool for easiest computation of membrane dimensions.

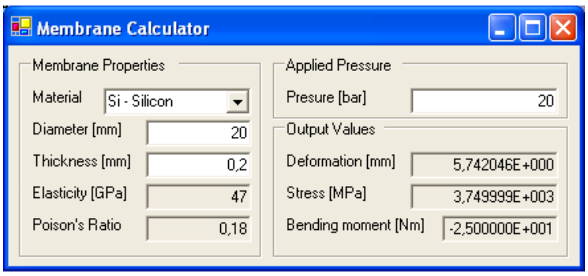


Figure 3: Tool for computing dimensions of membrane

From resulting dimensions of tantalum membrane we were able to design capsule of pressure sensor and measure behavior of mechanical and optical part of sensor.

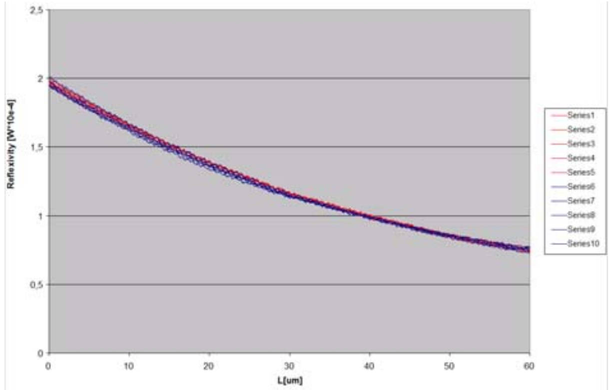


Figure 4: Reflective characteristics for tantalum

For validating of measured results was created mathematical model of optical and mechanical part of pressure sensor. Optical part of created mathematical sensor is based on the basic physical principles. On figure 5 is shown schematic of fiber ending with optical emitting characteristic. Surface m_1 creates optical fiber ending and surface of light source and surface m_2 is reflective membrane. Reflected light power is reflected back to the m_1 and projection of this reflected light power is represented by surface m‘$_1$. As you can see only small part of emitted light power is linked back to optical fiber.

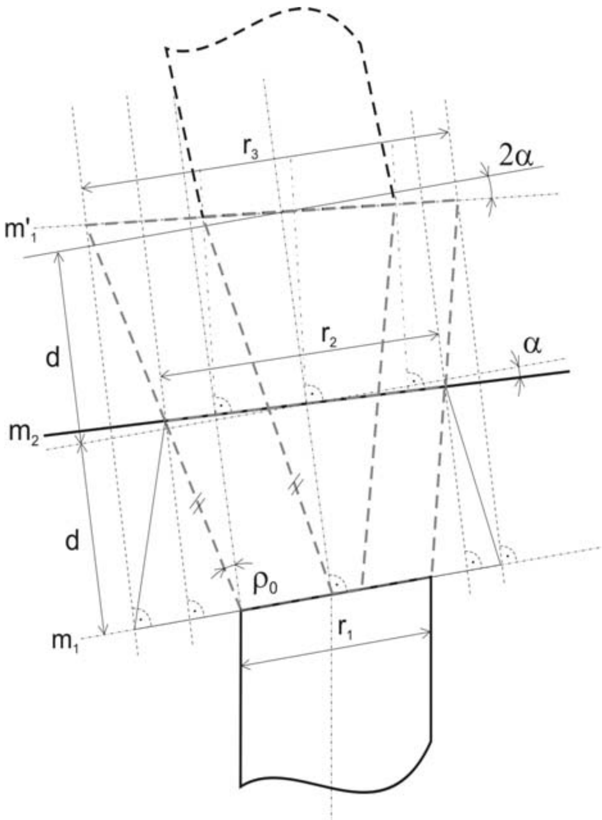


Figure 5: Drawing of emitting area of optical fibre ending

$$r_e = 2 \cdot \left[\rho_0 - 2d \cdot \sin\left(\frac{\lambda}{\pi \cdot n \cdot \rho_0} \right) \right]$$

Value of effective size of active part of optical fiber is given by equation (1).

$$(x, y, z) = E_0 \frac{\rho_0}{\rho(z)} \cdot \exp\left\{ -j\left[kz - \eta(z)\right] - r^2 \cdot \left[\frac{1}{\rho^2(z)} + \frac{jk}{2R(z)} \right] \right\} \quad (1)$$

For value of light energy we can derive equation (2).

(2)

From these equations and from equations for membrane deformation in dependence of applied pressure we are able to compile complete model of pressure sensor.

This model was created in Matlab environment and allows us complete simulations of optical pressure sensor and all used system descriptions are very valuable for improving and eventually compensations of sensor's output characteristic. That helps us in effort to improve sensor's output characteristic and eliminate influence of nonlinearity, compensation sensor's errors (zero, maximum and drift), suppression of temperature influence and dithering of supply voltage or current.

5. CONCLUSION

The new pressure sensor is composed of several different parts. We tested all of those parts independently on the rest of the sensor. The greatest benefit of the pressure sensor consists in new optical sensing module. Acquisition of this solution is in expected higher accuracy of pressure measuring, galvanic isolation of the resulting sensor compared to a classical sensor used in abroad and absolute endurance against external magnetic and electric interference. Next advantage is in zero emission of measuring optical signal into sensor's surrounding environment and signal transmission ways. It makes this sensor's attribute ideal against tapping. The next contribution of this solution with built-in intelligence is in possibility of adaptability pressure sensor for consumer requirements. Output characteristic and used materials guarantee excellent parameters for using this type of pressure sensor in industrial environment, explosive environment and environment with high electrical and magnetic interference. Very important for resulting of sensor's accuracy and sensitivity is membrane. We tested standard membrane surfaces and materials in effort to find optimal membrane surface profile and surface structure.

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