Proceedings of the 17th International Conference on Force, Mass, Torque and Pressure Measurements,
IMEKO TC3, 17-21 Sept. 2001, Istanbul, Turkey

TRADEC - A New Reduced Power Consuming Magnetoelastic Force Transducer

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Abstract

In the paper it is presented a possibility to reduce power demand of a magneto elastic laminated core transducer based on the using of a combination of electromagnetical active and passive sheets.

Due to the different stiffness of the two types of sheets it is used the finite element method for the strain and stress field analysis in the sheet stack in three cases: sheets in contact without / with friction and adhesive stacked sheets. The results of this simulation are compared with the experimental results on the basis of some performance analysis criteria.

1. Introduction

The classical magneto elastic force transducers [1] operating as amplitude modulated systems in which the carrier frequency is the power unit frequency and the modulating signal is created by the time variation of the applied force have the disadvantage of being great energy consuming because the magnetization regime of the measuring zones from the magnetic circuit is brought near saturation for the purpose of improving metrological characteristics on one side and the total magnetization power depends on the number of the measuring zones from the core therefore on the transducer rated force on the other side.

To keep the absorbed power between reasonable limits the carrier frequency must have low values usually, 50 Hz or values close to this.

Such a limitation leads on the other hand to low values of the response time and of the sensitivity at the force variation, the important parameters in controlling some technological processes.

The most radical method to reduce the consumed power consists of reducing the magnetic material quantity from the transducer body [2].

Transducer described in the paper [3]

called further on "Tradec" unlike other constructions is made of magnetic material only, but this is used in such a way that only a small part of this material to be active magnetically.

For this "Tradec" transducer is achieved of two types of sheets a first type named active sheet (Fig.1 a) in which the magnetic field is closed through the magnetic material from the measuring zone and a second type named passive sheet (Fig.l b) in which the magnetic field is closed mainly through an air gap created specially, the number of active sheets from the stack being more smaller than the number of passive sheets

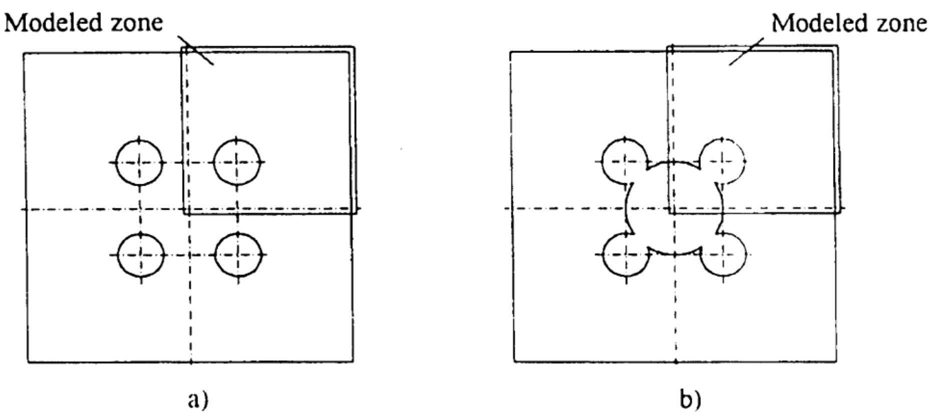

Figure 1. The sheets of the "Tradec" transducer: a) active sheet; b) passive sheet

As a result "Tradec" behaves as an inhomogeneous body mechanically and it behaves as that the passive sheets would be made of nonmagnetic material from the magnetic point of view and so the consumed power should be theoretically reduced in the ratio between the active to total sheet number in the transducer body.

In homogeneity of the transducer body is due to different stiffness of the two types of sheets and the optimising of this transducer construction was made on the basis of the finite element method analysis for the assembly made by the two sheets.

An objective of this study was made up by the settling of an adequate model for the contact between sheets leading to a stress and strain field respectively, closer on the real state.

The simulation results were compared with measurements on actual transducers.

2. Finite Element Analysis

The analysis performed with ANSYS

program [4] had especially in view the determination of the phenomena that take place in the measuring zone the relative displacements of the active and passive sheet elements respectively the displacements that must be limited to avoid the adhesive detachment or which can determine the increasing of the overall hysteresis of the measuring device.

Manufacturing technology stipulates the sheet slicking in stack at increased pressures and temperatures leading to an increased space factor. At the intentional detachment of the sheets from the stack it is found that the adhesive is to a great extent expelled between the sheets the adherence being provided by adhesive islands and by intimate contact achieved between the steel sheets.

As a result there were studied three contact models: direct contact with friction, direct contact without friction and contact by adhesive.

2.1.Employed Model

The structure of the two sheets shows two symmetry planes therefore it could be studied only a quarter of each sheet structure using corresponding symmetry criteria.

The geometrical model of the sheet in stack structure is made of 32 volumes 149 areas and 224 lines. For the finite element analysis a solid three dimensional (hexahedron with 8 nodes) element STIF45 in ANSYS was used. The model with finite elements contains 3655 nodes and 3292 elements. The maximum number of the equations of the problem is 10845 and the maximum front width is 675.

2.2.Boundary Conditions and Applied Load

On the finite element model of the two sheets assembly there were applied symmetry conditions in symmetry planes. The model was loaded with a uniformly distributed load of 10 daN/mm^2 value. In Fig. 2 boundary conditions and applied load are shown. Degrees of freedom on the global direction X were connected for all the nodes being in the section where the load is applied

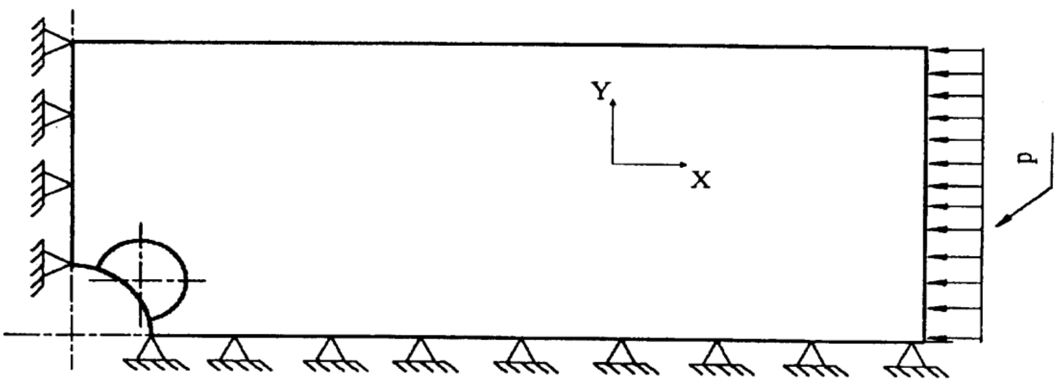

Figure 2. Boundary conditions for FE mode

2.3. Results

2.3.1. The Study of the Active Sheet Separately

In the first stage it was made the analysis of the stresses and strains in the active sheets the classical transducer is made. The maximum von Misses equivalent stress acquired is σ_{ech}= 30.6 daN/mm^2.

2.3.2. The Study of the Active - Passive Sheet System in Direct Contact with Friction

Between two coincident nodes of the two sheets there were considered contact elements (STIF52 in ANSYS).

Contact elements have been thought to be "closed" in the initial state; these have a normal stiffness of 0.1 x 10^{11} N/mm more higher than of the adjacent elements; friction coefficient intersheets is μ = 0.11. By using contact elements the problem becomes non-linear and requires an iterative solving. To reach the convergence 40 iterations were required.

The maximum equivalent stress got in the active sheet is σ_{ech}=52.8 daN/mm^2, and in the passive sheet σ_{ech} = 37.5 daN/mm^2.

In Fig. 3 it is shown the deformed shape of the active - passive system, the strains being multiplied by a factor D = 20000.

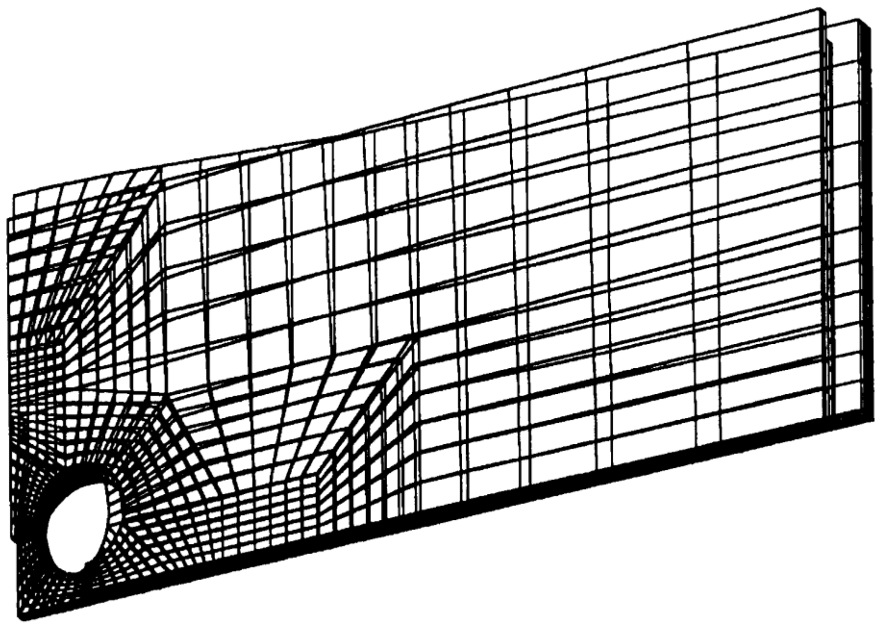

Figure 3. The deformed shape of the active - passive system for direct contact with friction

2.3.3. The Study of the Active - Passive Sheet System in Direct Contact without Friction

Between the two sheets there is a gap equal with the adhesive thickness. In this case the problem is linear because contact elements are not used. This case was taken into account to be able to determine the influence of the adhesive insertion on the relative displacement between the active and passive sheet. The maximum equivalent stress got in the active sheet is σ_{ech}= 43.7 daN/m^2; in the passive sheet the maximum equivalent stress is σ_{ech}= 31.4 daN/mm^2 .

In Fig. 4 it is shown the deformed shape of the active - passive system, the strains being multiplied by the same factor D = 20000.

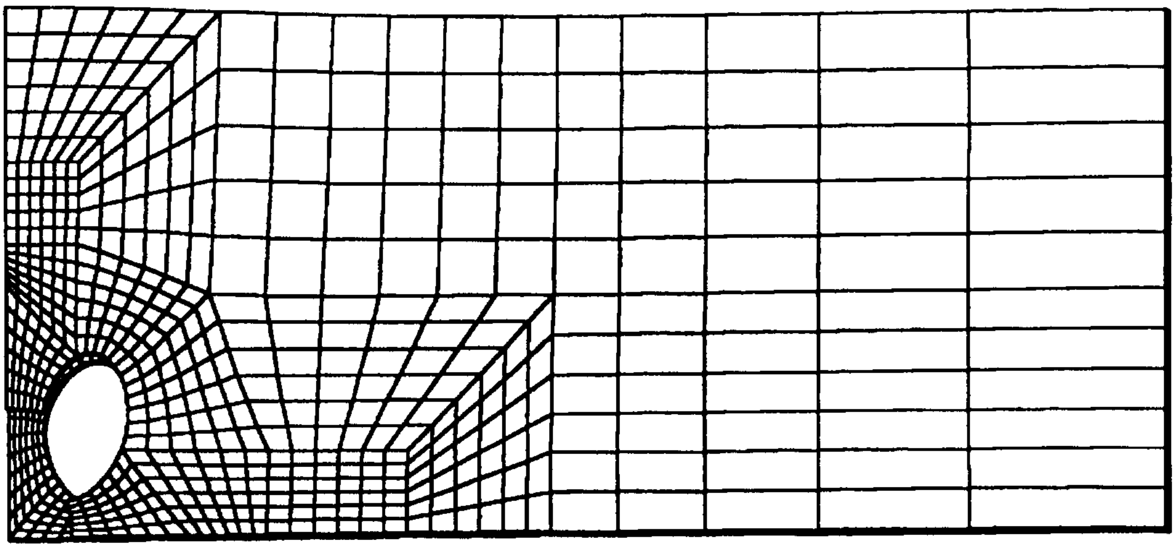

Figure 4. The deformed shape of the active – passive system for direct contact without friction

2.3.4. The Study of the Adhesive Stacked Active - Passive Sheet System

Between the two sheets there was considered a gap equal with the adhesive thickness and between the two coincident nodes of the two sheets there were introduced equivalent stiffness corresponding to adhesive on the normal direction and on the two tangential directions by means of STIF27 type elements. Stiffness of these elements were determined depending on the element of volume surface on which it is joined using relations:

$$K_N = E \cdot A / d \qquad (1)$$

$$K_T = G \cdot A / d \qquad (2)$$

Where: A - element of volume area the adhesive element is joined.

d - gap size equal with the adhesive thickness (50 times smaller than the sheet thickness).

Maximum equivalent stress in the active sheet is σ_{ech} = 37.5 daN/mm^2; in the passive sheet the maximum equivalent stress is σ_{ech} = 28.3 daN/mm^2.

In Fig. 5 it is shown the deformed shape of the active - passive sheet system, the strains being multiplied by factor D = 20000.

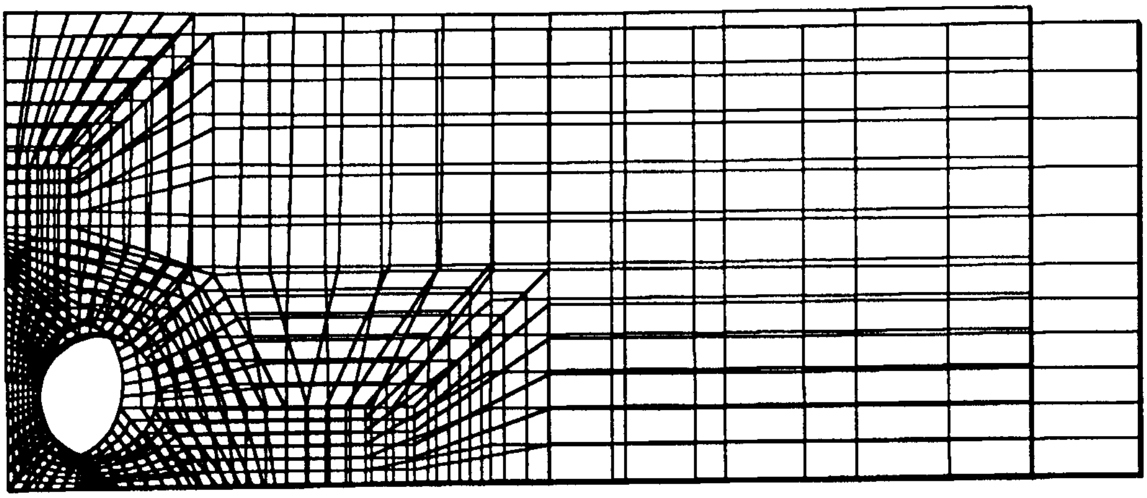

Figure. 5 The deformed shape of the adhesive stacked active – passive sheet system

2.4. Result Interpretation

In case of the friction contact sheets the maximum equivalent stress acquired is higher than in the other two cases and comes out from the linear area of the material characteristic. The relative displacements between the two sheets are the biggest reaching 1 x 10^{-3} mm.

For the active contact sheets without friction it is noticed a decreasing of the maximum equivalent stress value with 18% with regard to the precedent case but what is more important the relative displacements between the two sheets diminish practically with an order of magnitude at 0.1 x 10^{-3} mm.

In case of the sheets joined by adhesive the maximum stress acquired is the most reduced (37.5 daN/mm^2 for the active sheet) and relative displacements decrease to 3.5 x 10^{-6} mm.

In comparison with the classical transducer the maximum stress in the active sheet of "Tradec" is only 22% higher for the same applied load.

3. "TRADEC" Transducer Designing Criteria

The results of the finite element analysis taking into account the adhesive layer have been experimental by testified for "Tradec" design.

The following criteria were stated to analyse the new transducer performances:

a) $$k_A = \frac{active\ sheet\ No\ in\ stack}{total\ sheet\ No\ in\ stack} < 1 \qquad (3)$$

$k_A = 1$ For classical magneto elastic transducer

b) $$k_M = \frac{Factor\ of\ merit\ for\ k_A < 1}{Factor\ of\ merit\ for\ k_A = 1} \qquad (4)$$

c) $$k_U = \frac{primary\ voltage\ drop\ for\ k_A < 1}{primary\ voltage\ drop\ for\ k_A = 1} < 1 \qquad (5)$$

d) $$k_P = \frac{absorbed\ power\ for\ k_A < 1}{absorbed\ power\ for\ k_A = 1} < 1 \qquad (6)$$

Factor of merit (C_M) is given by the ratio between the transducer sensitivity $\Delta U = U_{2N} - U_{20}$ at the rated force and zero signal U_{20}:

$$C_M = \Delta U / U_{20} \qquad (7)$$

Though the power consumption decreasing bears especially high force transducers as those used to measure rolling force (1 - 32 MN) the widespread using of the magneto elastic transducers for small forces takes the full advantage from "Tradec" in competition with strain gauge transducers.

During the tests the number of active sheets in the stack was varied from 1.1% up to 32% and the active sheet distribution in the stack was varied from their uniform distribution to their concentration in the middle of the stack.

To avoid end phenomena at the force transmission on the relative large surface of the transducer the packing begins and ends with a passive sheet group.

The tests were done for overloads up to $2F_N$ with linearity and hysteresis error determination before and after overload.

It was found that measurement errors are not generally affected by the new design; this is particularly important because it shows the additional stresses arising in the sheet stack do not exceed the limit given by the finite element analysis taking into account the adhesive.

It is estimated that the optimal value for k_A is 30% for high force transducers (over 1MN) and about 10% for smaller forces. The difference is not the result of the metrological property impairment but it results from the intention of an accurate integration of the applied force.

The factor of merit has generally an increasing tendency at the active sheet number decreasing the variation limits being between 2 and 9 with regard to 2 to 4 at the classical transducer.

Reducing of the primary voltage drop and therefore of the absorbed power is proportional to k_A as it was foreseen in the theoretical analysis.

4. Conclusions

1. "Tradec" magneto elastic transducer has the same metrological properties as the classical transducer at a power demand of at least 3 times smaller.

2. For its design two types of sheets - one called active and the other passive achieved from the same material are used.

3. By achieving the transducer body from the same material the temperature errors are not affected by employed construction.

4. Finite element analysis of the active - passive sheet assembly taking into account the adhesive material between sheets cannot be avoided at an accurate analysis of the phenomena taking place in measuring zone of the transducer because the stress field in the transducer structure can be considered neither plane stress nor plane strain. Relative displacements of the active and passive sheet elements have so small values that the adhesive detachment is not possible - a fact confirmed by the performed tests.

5. At forces under 100 kN it can be reached a power demand reduction of 6 to 10 times which brings the magneto elastic transducer in direct competition with strain gauge transducer from this point of view.

5. References

[1]. Patent USA No 2, 895, 332.

[2]. Patent USA No 4, 474, 069.

[3]. Patent RO No 103778.

[4]. De Salvo G.J., Gorman B.W., ANSYS *Engineering Analysis System User's Manual; Revision 4.4.A Swanson Analysis Systems*, Houston, Pa 1989.

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