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EXPERIMENTAL RESEARCH OF AN INDUCTIVE DYNAMIC DRIVE FOR DIFFERENT COIL POWER SUPPLY SYSTEMS

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Abstract − An inductive dynamic drive is nowadays a commonly used servo-motor everywhere where a significant dynamics of the linear displacement is required. In industrial environment the dynamic drives are commonly used in ultra fast hybrid switches for opening the contacts. At the same time, choice of the parameters and type of power supply of the drive coil, which influence the generated power is very important due to possibility of occurrence of unfavorable vibration and even permanently deformation of the disk. The paper presents the results of an experimental research concerning the inductive dynamic drive behaviour for three different power supply circuits of a coil, i.e. bidirectional one, a one way circuit with a reverse diode and a one way circuit without a diode. During the research the coil current and the disc movement were recorded. The last one was measured with use of an optimeter. At the end of the paper the related analysis of the received results is presented.

Keywords: inductive dynamic drive, coil current, disc movement

1. INTRODUCTION

Inductive dynamic drive is used in various technical industries: in mechanics as pressing part of dynamic drive, in military as an electrodynamic weapon, and in electrotechnics as an element of the breakers systems.
Direct Current Hybrid Circuit Breaker presented (DCHCB) in Fig.1 is a device using inductive dynamic drive in its construction [1]. The drive has a very short switching off time, around 1 ms, which allows to obtain limited current $I_0 \leq 3{,}6$ kA at expected current I_p=60 kA and circuit's time constant of 20 ms. The breaker consists of two vacuum chambers: the main and the auxiliary ones. Both of them are supplied by the same inductive dynamic drive. The control block is an element which function is to detect short circuit and in results to start IDD. If the movable contact of the main chamber moves in some distance, then the control block also switches an energy electronic part (transistor IGBT). Then there occurs rapid flow of the short circuit current into the branch with transistor, which results in going out of arc in the main vacuum chamber. After the arc disappears IGBT switches off and consequently the arc in the auxiliary chamber goes out as well. Then the current flows to the branch with multifunctional protection part, where the varystor is placed. Finally, this system brings the short circuit current to zero.

Another type of a hybrid switch is a switch of type AC HCLID (AC Hybrid Current Limiting Interrupting Device [2]) presented in Fig. 2.
A drive of this type is build in such a way that the contacts segment CC is placed in the air and the purpose is that during opening of the contacts an ignition of the arc will not happen [3]. Switching off the current is obtained by opening CC and simultaneously providing contra current from the commutation circuit with capacity of C_k via thyristor T_k. The contacts segment CC is opened by plastic deformation of the movable end by the electrodynamic force of inductive dynamic drive F_{ed}.
It is worth to underline that proper operation of the breakers above mentioned to a large extend depends on good characteristics of the connection contacts drive. The switch will work only if ideally synchronized with the connection contacts movement, which requires immediate work of the drive after detecting a short circuit by the circuit detector. Therefore, in ultra fast hybrid switches usually IDD drives are used due to fulfilling the conditions above. In order to describe IDD parameters existing mathematics models are used. However, due to complexity of elctrodynamic, mechanical and termic phenomena which influence each other, there is no model taking into account their coupling. For this reason still experimental research of IDD is the main method of learning about and designing of these drives.

An inductive dynamic drive (IDD) consists of a coil supplied from a bank of capacitors and an inductive coupled secondary element called disc (Fig. 3, Fig. 4). The drive work is based on so-called Thomson phenomenon. Due to reduction of the coil resistance the impulse of the current in the circuit obtains a high value. As a result a strong impulse of the inductive field induces a high eddy current in the disc. Interaction of magnetic fields results in a repulsion of the disc. The drive ensures an adequately quick dislocation of the driven moving element. In case of breakers these elements are contacts which break off the short circuit current.

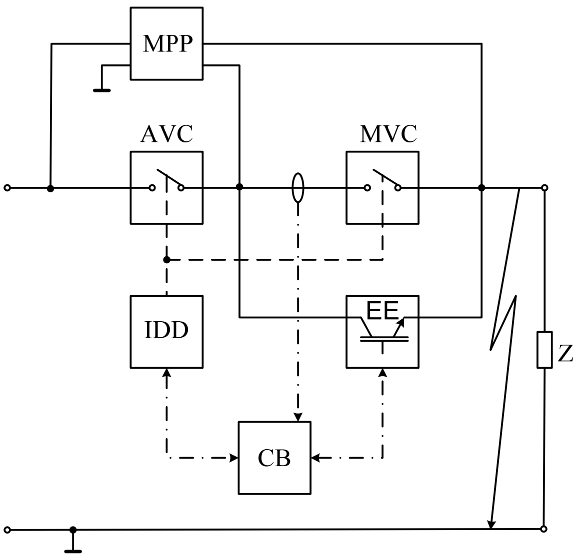

Fig.1 Block diagram of a hybrid switch type DCH 0.8/400:
MVC – main vacuum connection contacts; AVC – auxiliary vacuum connection contacts EE- electro-energetic part (transistor IGBT), IDD – inductive dynamic drive, MPP – multifunctional protective part, Z – load, CB – control block.

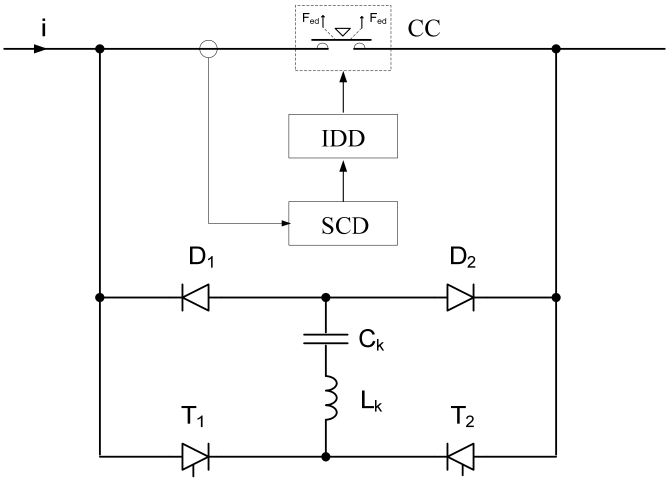

Fig. 2. Diagram of a hybrid switch type AC HCLID
i – switched off current, C_k - capacity of the commutation circuit, L_k - inductance of the commutation circuit, T_1,T_2 – thyristors, CC – connection contacts, F_{ed} – electrodynamic force of the drive, $D_{1,2}$- diodes, SCD – system of current detection IDD.

The selection of the system parameters resulting the greatest dynamics is difficult since on one hand the dynamics rises together with the reduction of the disc mass, on the other hand, the reduction of the disc thickness causes an increase of vibration, and therefore a stress of the disc.

Simulation research conducted on the existing mathematical model of the drive shows that if the ratio of the produced force to the mass is too large, the excess of admissible stress level takes place. Whereat, the space time distribution of the force has a fundamental influence on the stress level. A bidirectional switch is a classical supply system of the coil in the drive. The current of the coil and the disc, and hence the force, have then the oscillative nature with an oscillation frequency mainly depending on RLC parameters of the coil circuit.

A way to obtain a force of an aperiodic nature while keeping a possibly small resistance of the power supply circuit is to use a reverse diode connected in parallel to the coil.

The aperiodic nature of the current can decrease the value of the induced eddy currents in the disc and hence the system will decrease its dynamics. On the other hand, the aperiodic nature of the force decreases the disc stress.

Therefore there appeared a necessity of experimental research with use of both kinds of the coil power supply circuits. Additionally, the system with a one-way switch without a reverse diode was examined.

Fig.3. The coil with an inductive coupled disc.

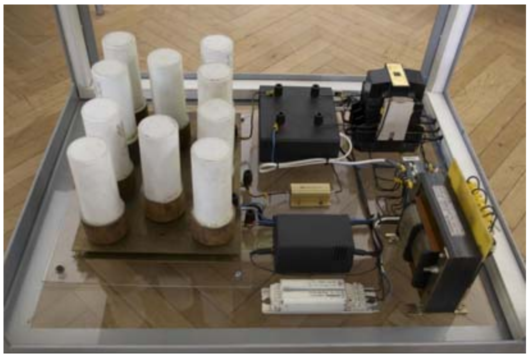

Fig.4. The bank of capacitors.

2. DESCRIPTION OF A METHOD

The existing measurement system (Fig.5) was used in order to carry out the experimental research. The system gives a possibility to register the current in the coil circuit and the disc movement [6]. The optimeter which construction and verification were presented in [4] was used for registering the displacement. The coil current was registered with use of a low-inductive 1 mΩ measuring shunt R_b. Both courses were sent to the computer and worked out in the Mathcad environment.

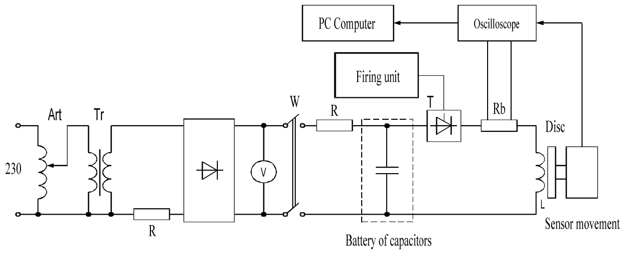

Fig.5. IDD measurement system.

The research for the three most often used coil power supply circuits was carried out. These power supply circuits are: a bidirectional switch which is a thyristor with push-pully connected diode (Fig. 6a), a one way switch (thyristor itself) with a reverse diode connected in parallel to the coil (Fig.6b) and a one way switch (thyristor itself) (Fig.6c).

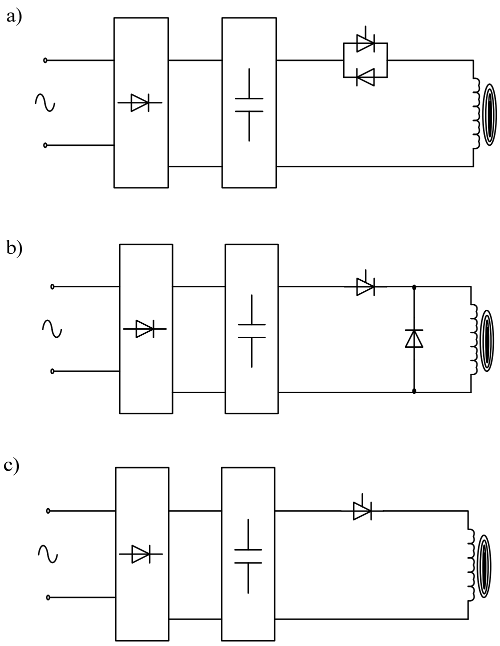

Fig.6. The coil power supply circuits of the IDD drive:
a) with the bidirectional switch, b) with the one-way switch and the reverse diode, c) with one-way switch.

Series of experiments for several capacities of the bank of capacitors were conducted for each of these power supply circuits. Whereat, each time a power supply voltage fulfilled the condition of constancy of the initial capacitor's energy *W*.

$$W = \frac{C \cdot U^2}{2} = const. \tag{1}$$

Each capacitor from the bank has a permissible transient current higher than 20kA. Parameters of the researched inductive dynamic drive are presented in table 1.

Tab.1. Selected data of the IDD under consideration.

Initial energy of capacitor: E=50J	Capacitance of capacitor: C=500÷1000μF
Outer radius of disc: R_o=7 [cm]	Outer radius of coil: r_o=7 [cm]
Inner radius of disc: R_w=4.5 [cm]	Inner radius of coil: r_i=4.5 [cm]
Add mass: 0.28 [kg]	Winding of coil z=24
Material of disc: duralumin Disc thickness h=4 [mm]	Coil thickness: h_c=1 [cm]

3. EXPERIMENTAL RESULTS

The results of the registered coil current and the disc displacement for selected capacities of 1000, 900, 700 and 500 μF of the capacitors bank for the coil power supply system with a bidirectional switch (Fig. 6a) were presented in Fig.7a and b.

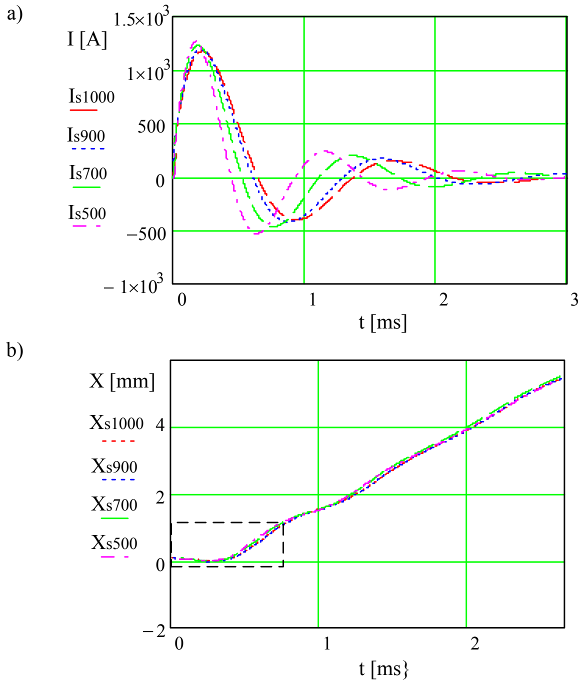

Fig. 7. The curves of the coil current (a) and the disk displacement (b) for different capacities of the bidirectional switch from Fig. 6a.

Adequately, in Fig. 8. and Fig. 9. the curves with reference to the coil current and the disc displacement are presented for supply systems with a thyristor and a reverse diode (Fig. 6b) in one case and with the thyristor alone (Fig. 6c).

Taking into consideration the curves presented in Fig. 7ab, Fig. 8ab and Fig. 9ab it can be stated that in case when the required distance exceeds 2mm in no power supply systems a significant influence of the capacity was observed.

Whereas in the system only with the thyristor (Fig. 9b) the disc reached the distance of 4mm about 130 μs later for capacity C=500μF comparatively to the C=1000μF case.

However, while observing enlarged curves to the range of 1mm it was noticed that in case of a smaller capacity in each power supply system, the disc had achieved the way of 1mm quicker.

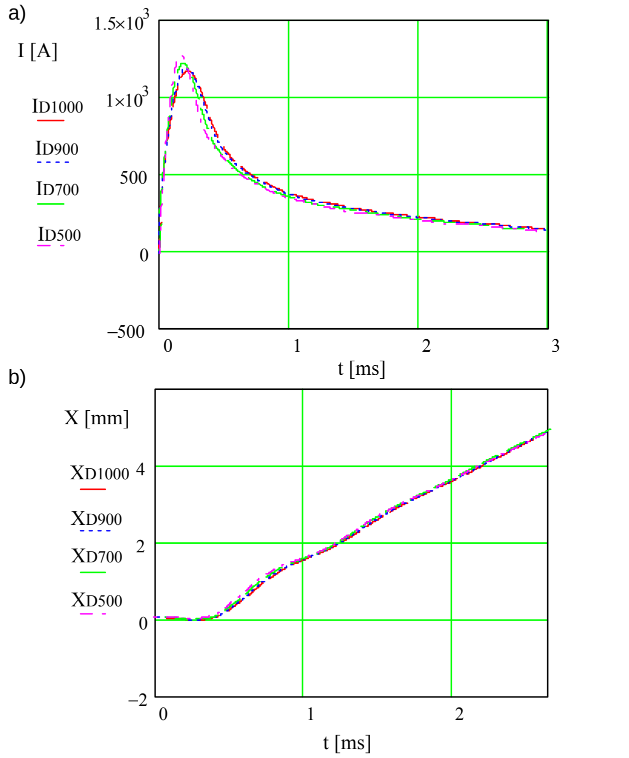

Fig. 8. The curves of the coil current (a) and the disc displacement (b) for different capacities of the one way switch with a reverse diode from Fig. 6b.

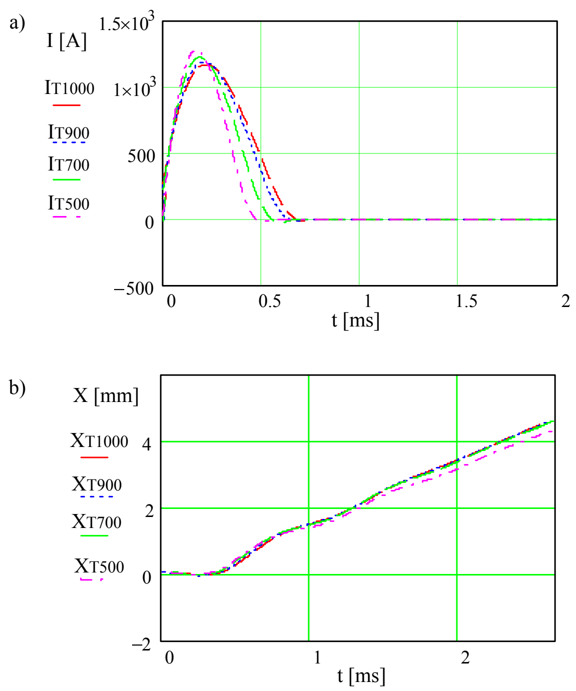

Fig. 9. The curves of the coil current (a) and the disc displacement (b) for different capacities of the one way switch from Fig. 6c.

For example, in the bidirectional system the disc with the power supply from the capacitors bank with C=500μF reached the coordinate x=1mm 40μs earlier than with capacity of C=1000μF (Fig.12b).

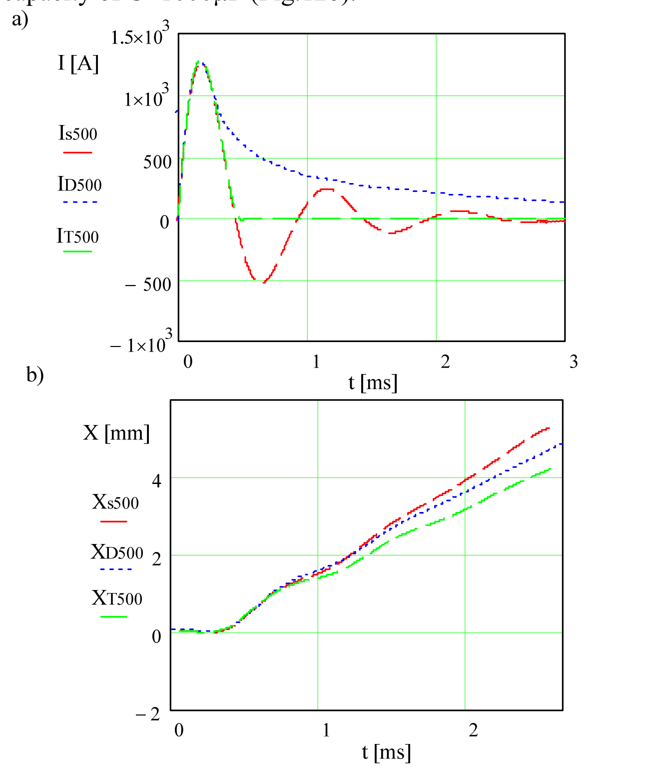

Fig.10. Comparison of curves for the capacity C=500μF for a bidirectional switch, a one way switch with a reverse diode and a one way switch alone.

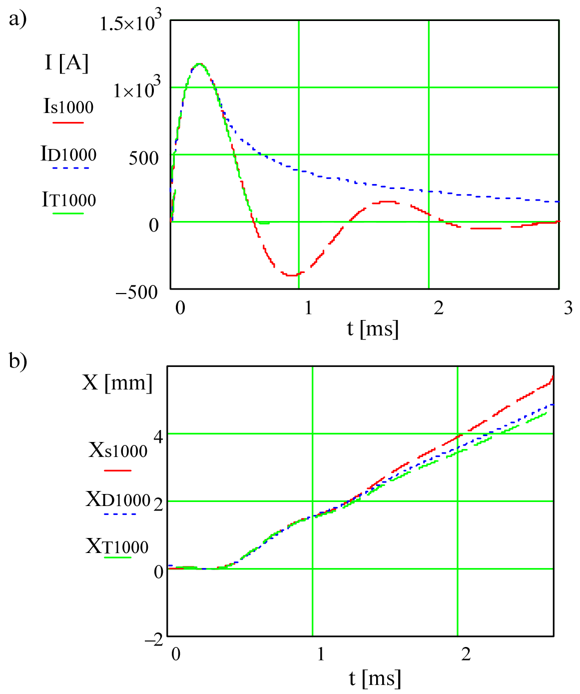

Fig.11. Comparison of curves for the capacity C=1000μF for a bidirectional switch, a one way switch with a reverse diode and a one way switch alone.

By comparing courses of the disc for different power supply systems of the same capacity, it was examined that for the distance exceeding 1mm the bidirectional system (Fig. 10b) began to dominate.
For example, for C=1000μF the disc displacement reaches 4mm in the bidirectional system about 200μs earlier than in the one-way system with a reverse diode (Fig.11b).

Whereas, for displacements up to 1mm all three power supply systems show similar proprieties for all the examined capacities. This is due to the fact that first half-waves of the current (for the same capacity) cover each other in all systems.

4. CONCLUSION

The same initial value of the energy of capacitors should give the same maximum final speed of the disk. That would happen if the system had the same efficiency in every case.

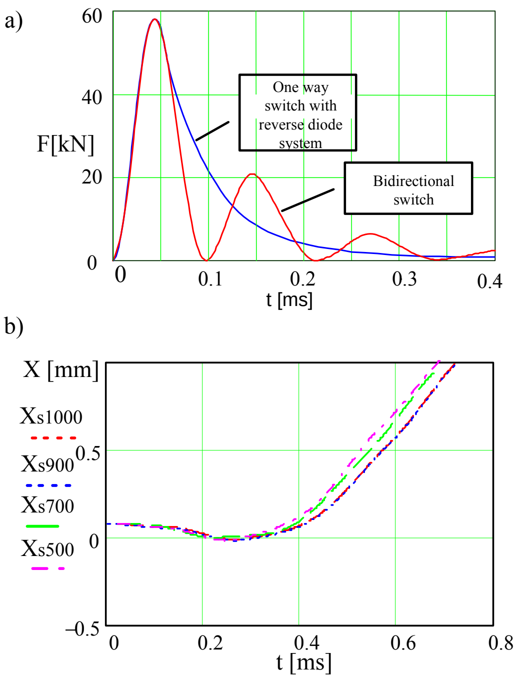

Fig.12. a) The curve of a resultant force interacting between coil and disc for the bidirectional switch system and one way with reverse diode system;
b) Magnification of the window from Fig.7b for the bidirectional switch in a range 0-0,8mm.

However, the efficiency of the drive depends on some factors and at a constant value of disc mass is for sure different for various capacities and different power supply systems. Moreover, the moment of the measurement i.e. the range of the displacement has a crucial meaning. While observing curves of calculated forces obtained from the bidirectional system supply and the one way system with a reverse diode presented in Fig. 12a, one can notice that depending on the moment of the measurement, the integral from the force can be greater once for one system, and once for the second one.

Taking under consideration the results of explored systems one can ascertain that for the displacement greater than 1 mm the best dynamic characteristics are shown by the drive with bidirectional switch. Additionally, for the above range, capacity has a smaller influence on the time of attaining the position on the condition that the beginning energy is constant. Of course this means an increase of the beginning voltage for a smaller capacity of the capacitors bank. The worst characteristics were noted for the system with one way switch (thyristor itself), which seems obvious, because it disconnects in the moment of the non-zero value of the voltage (energy) of the capacitors bank.

While suggesting better proprieties of the bidirectional system one ought to remember about negative mechanical results of the pulsating force, especially at frequency close to the eigenfrequency of the disc [5].

5. REFERENCES

[1] J. Czucha, J. Woloszyn, M. Woloszyn, ”The comparison of ultra fast A.C. hybrid circuit breakers with GTO and IGBT”, 35th *Universities Power Engineering Conference UPEC*’2000, Belfast, 6-8 September 2000.

[2] Jakubiuk K., Jankowski P., Wołoszyn J.: Commutation of current in A.C. hybrid circuit breaker, XXIII Seminar on Fundamentals of Electrotechnics and Circuit Theory, Ustroń, Poland, p. 313-316, May 2000

[3] P. Jankowski, S.Rymkiewicz, ”Stress analysis of magneto-elastically vibrating disc”, *Acta-technica CSAV* vol.53 no2 pp.121-139 Praha 2008.

[4] P.Jankowski, B. Dudojć, J. Mindykowski, ”An optimeter designed to register ultra fast displacements”,*16 Exploring New Frontiers of Instrumentation and Methods for Electrical and Electronic Measurement IMEKO* 2008 Florence 22-24 September.

[5] V.V. Kulagin, ”Optical displacement transducer with pulsed pump for experiments with probe bodies”, *Journal of Optics B: Quantum and Semiclassical Optics*, vol.2, n°. 2, 2000 , pp. 100-104(5).

[6] D. Perla, R. Gaudino, G. Perrone, S. Abrate, ”Optical displacement transducer, displacement measurement system and method for displacement detection there from”, US Patent (n°.:7323678) Issued on January 29, 2008.