

METROLOGICAL ASPECTS OF THE INDUCTIVE DYNAMIC DRIVE RESEARCH

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Abstract: The article is the synthetic description of the methods applied by authors to assign the quantities characterizing the properties of an inductive dynamic drive. The used measuring methods were divided as follows: 1) direct methods which make it possible to mark the searched quantities on the basis of direct observation of the tested measuring system, 2) indirect methods which use obtained results (in direct method) to determine the measured quantities. Very often they require a more complex computer processing or even the use of mathematical models. The experimental registration of coil current and the disc displacement was classified as a direct method. The simulating determination of speed, the acceleration and the state of stress in the disc with the use of the coil current and the displacement were classified as an indirect method.

Keywords: drive, displacement, acceleration, deviation, measurement

1. INTRODUCTION

Inductive-dynamic drive (IDD) is a type of electrodynamic drive (Fig. 1). It consists of the coil which is supplied from capacitor battery and the movable secondary element which is a well conducting, most often an aluminum disc. The RLC parameters of the coil circuit should have the small values. Hence, the current of coil and magnetic field have impulse character. Such impulse field induces eddy currents of large values in the aluminum disc. This type of drives belongs to the quickest ones not only because of the possibility of large accelerations achieving ($a(t) > 100000g$), but also because of short time reaction. The reaction time is measured from the moment the impulse appears in the thyristor gate (Fig. 3) until it reaches an expected moment of the displacement. This fact and the repeatability of this process make these drives superior to other kinds of drives such as spring, electromagnetic or explosive. The above mentioned features caused that they are the essential element of the ultra-rapid circuit breakers (HCB) [2].

HCB are the combination of semi-conductive elements and a contact segment where the disc of the IDD is a

movable point of a contact (Fig. 2). Because of such hybrid approach, HCB reach a very short time of switching off at the lack of arc.

The process of HCB working might be divided into three stages:

- 1) the detection of a short-circuit current (the SCD), the start of IDD and the commutation of current from CS to EE,
- 2) the commutation of the current from EE to PE, (after reaching a suitable gap between contacts)
- 3) disconnection of the current by PE.

The above mentioned stages show that the IDD is a very important part of the HCB and it has to be characterized by high dynamics, the repeatability of the process and the long-lasting reliability. The IDD fulfils these features on condition that all its parameters are selected correctly.

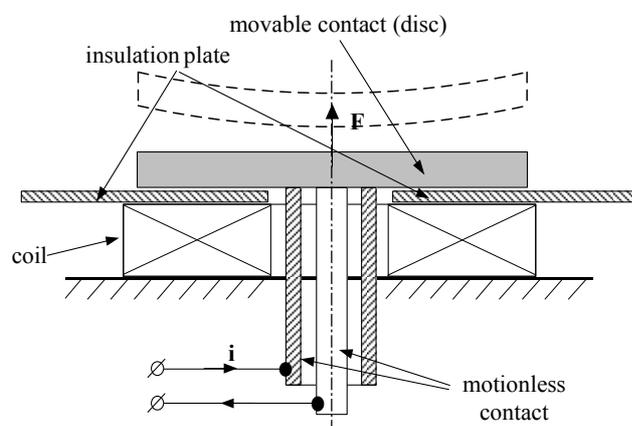


Fig.1 Construction of contact-IDD system and deformation of disc

The phenomena occurring in the IDD can be of a magneto-thermo-elastic character.

The IDD model which analyses all these phenomena and takes their coupling into account does not exist yet. Therefore the research of IDD still requires experiments. To design the IDD one should select such parameters to fulfill the following conditions by IDD:

- a) the suitable dynamics - determined on the basis of the courses of displacement, speed and acceleration of the disc,
- b) the guarantee of admissible level of tensions.

Unfortunately, these conditions are opposing ones. It is because the reducing the mass of the disc enlarges its dynamics, but simultaneously tensions of the disc increase. The increase of the disc dynamics at the decrease of its mass is realized by decreasing its thickness. However the thickness of the disc should be less than 3 skin depth because the subsequent layers do not take part in creating electrodynamic force.

On the one hand the experimental measurement of quantities mentioned in a) and b) is very difficult in realization, on the other hand it is economically groundless. Therefore, the disc displacement and coil current is determined by experimental method. However the time-spacing distribution of magnetic pressure acting on the disc and the state of stresses were obtained by applying complex method (on the basis of mathematical models by using a registered coil current).

These quantities describing the features of an IDD are understood by authors as the “measurement” in the meaning introduced in [1] and interpreted in [8]. In this concept, the term “measurand” results from the generalization of the notion of quantity on time and/or space distributions of vectorial quantities, and on the relationships between them [8].

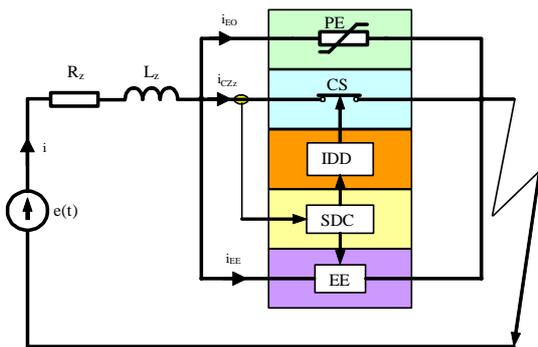


Fig.2 Block diagram of HCB in short circuit
CS- contact segment, IDD - inductive dynamic drive, EE – power electronics element, PE- protective element, SDC - system of current detection

2. MEASUREMENT SYSTEM FOR IDD QUANTITIES REGISTERED DIRECTLY

The measuring system which makes it possible to register the coil current and the disc displacement is presented in Fig.3. The current waveform is registered by using the low-inductive shunt R_k . The waveform of disc displacement, however, is registered with using of the optical sensor. The screen of oscilloscope with the example of the coil current oscillogram and the voltage signal from optical sensor is shown in Fig.4. The main element of the optical sensor is a photosensitive element. The photoelement is covered by the diaphragm which is connected to the disc. During the movement of the disc the displacing diaphragm exposes the photoelement. Therefore, the increasing output signal appears on terminals of the sensor.

The authors while testing the optical sensor [5,6] decided to apply a photodiode system that is a photoelement which was supplied from an external source E in reverse

direction (Fig. 3). This approach provided us with obtaining the larger sensitivity of optical sensor output characteristic. However, one should underline, that the consequence of such a choice was photodiode shot noise generating. (Fig.5).

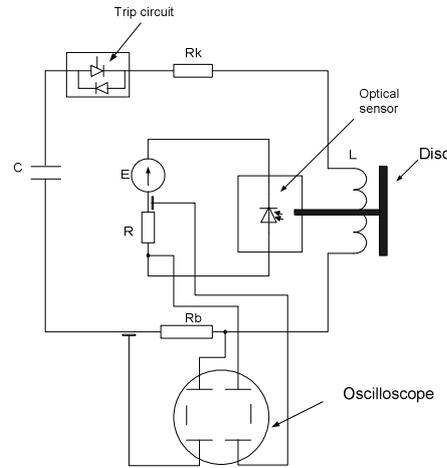


Fig.3 The measurement system to examine the coil current and the disc displacement

To obtain the displacement course in time function $x(t)$ one had to carry out conversion on the basis of the output characteristic U_p which is determined point by point (Fig.5) Hence, to achieve satisfactory filtration of the course U_p the mean square approximation was conducted applying the orthogonal Gram polynomials.

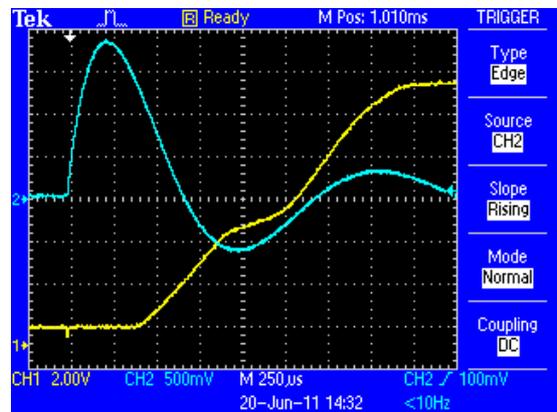


Fig.4 The oscillogram of the disc displacement and the coil current

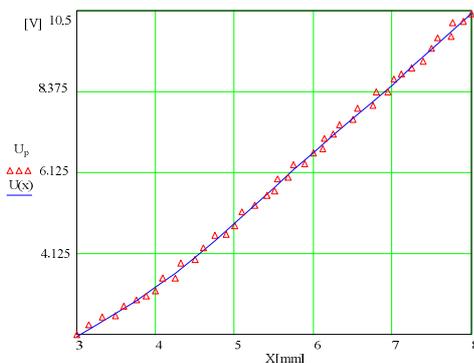


Fig.5 The output approximated characteristic -U(x)

Obtaining each point of optical sensor characteristic requires the shift of diaphragm with the use of the electronic micrometric screw point by point. Therefore it was necessary to determine how many measurement points one had to obtain for a satisfactory approximation because the value of mean square deviation is not the sufficient indicator of measurement points number. Hence, the authors carried out simulations with theoretical function for which disturbance was added [4]. The theoretical set of measurement points obtained in such way was approximated and mean square deviation was computed. The simulations were carried out for a various number of measurement points. Due to the fact that we came up with the analytical function, we additionally managed to determine the absolute and relative error. While observing the waveforms of mean square deviation (which was determined with the use of formula (1)) and relative error, the authors made a decision about the sufficient number of measurement points of the output characteristic which were determined point by point. Obtaining the precise displacement function $x(t)$ is essential to be able to use this function to determine speed function and acceleration function which were obtained as a result of differentiation(Fig.7).

$$\Delta st_n = \sqrt{\frac{1}{n+1} \cdot \sum_{i=0}^n (y_i - gL(x_i))^2} \quad (1)$$

Where: y_i -set of measurement points
 $gL(x_i)$ - approximating function

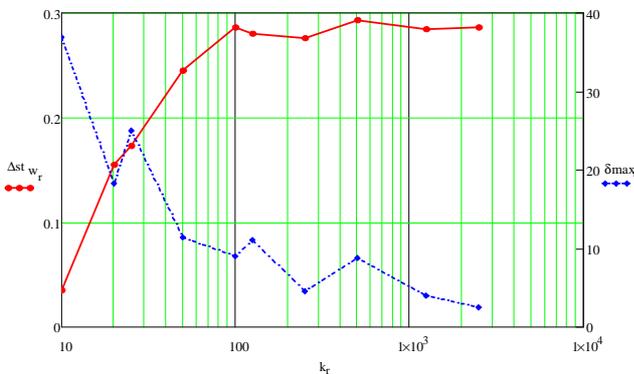


Fig.6 Mean square deviation and relative error in number of measurement function

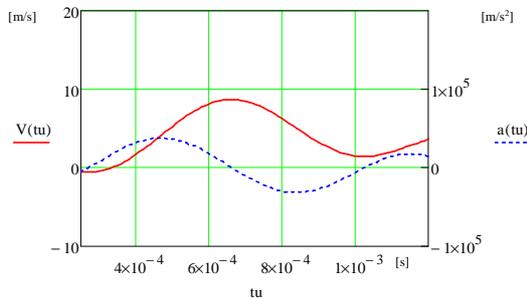


Fig.7 Trajectories $v(t)$ and $a(t)$ after differentiation $x(t)$

3. IDD STRESS ANALYSIS BASED ON THE INDIRECT MEASURING METHOD

In order to carry out a stress analysis it is necessary to determine magnetic pressure acting onto disc. The pressure can be determined on the basis eddy currents of the disc interacting coil current. There is the circuit model of IDD taking movable disc with coil coupling into account which enables us to determine such pressure [3]. The time of calculations with the use of a PC is too long especially when we have to use a dense mesh. The satisfactory approach was to build a simplified model in programme FLUX applying MES [7]. The coil current experimentally obtained was the input quantity for the above field model.

One should underline once again, that the coil field penetrating the disc is strongly attenuated as a result of skin effect. Hence, the pressure determined on the basis of the interaction of this field with eddy currents is treated as pressure acting onto the surface of the disc.

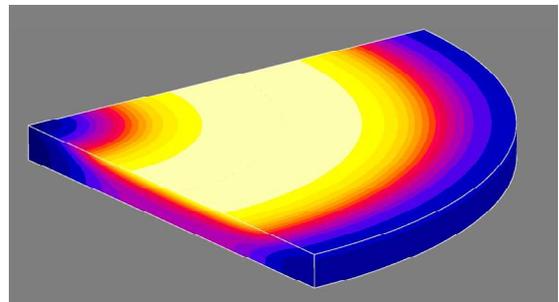


Fig.8 Current distribution of disc in Flux program

Thanks to the above approach we can determine the stresses of the disc with the use of mechanical model (MECH). The MECH model is based on the solution of vibrating thin plate equation [9]:

$$\frac{D}{\bar{\rho}} \nabla^4 w + \frac{\partial^2 w}{\partial t^2} = \frac{p(r, \varphi, t)}{\bar{\rho}} \quad (2)$$

The input function for MECH model is magnetic pressure $p(r, \varphi, t)$ (Fig. 9) which is obtained for each filament of the disc. In MECH model the disc is divided into 25 filaments.

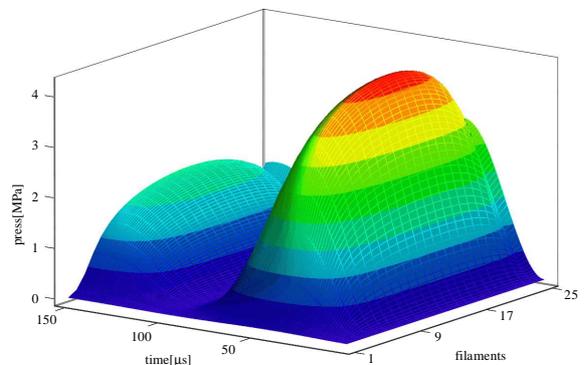


Fig.9 Time-spacing distribution of the pressure $p(r,t)$

The obtained solution of equation (2) makes it possible to determine reduced stresses in place and time function $\sigma_{zr}(r,t)$. The detailed analysis of MECH model was introduced in [3]. The main screen of the programme realizing MECH model is presented in Fig.10. The screen shows the trajectories of movement (the displacement of the midpoint and the centre of the mass of the disc) and the waveform of maximum values of reduced stress in the bottom part of the screen. The programme also shows the animations of the moving surface of the disc. Optionally one can open the subscreen with stress distribution along the radius. The course of this distribution confirms that the largest tension is in the centre of the disc.

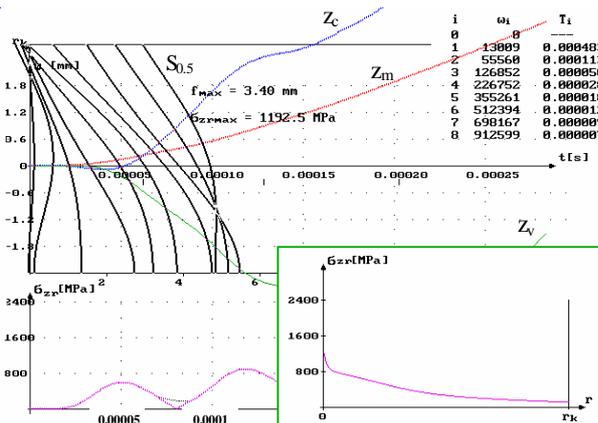


Fig.10 Main screen of MECH programme

On the basis of simulation in MECH model one can determine the essential course of reduced stresses in the disc thickness function (Fig. 11). The result of such investigation makes it possible to determine the minimum thickness of disc for which the maximum stresses will not exceed the admissible value.

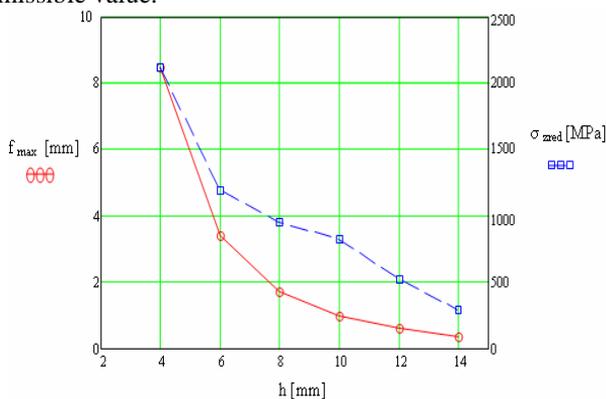


Fig.11 Results of maximal σ_{zr} and deflection for various thickness of the disc.

4. FINAL REMARKS

Such quantities as displacement, speed, acceleration and stress analysis decide about properties of IDD. The experimental - simulating methods presented in this paper enable us to design IDD which is dedicated to the specific HCB which switches off the short circuit in a defined

system. One should underline that the registration of disc displacement concerns only his centre. Hence, it could not be the basis to determine the distribution of stresses.

The solution of the vibrating disc movement and its computer realization was obtained on the assumption that the disc is ideally elastic, homogeneous and isotropic.

Additionally, an assumption is made that disc vibrations are not large. Hence, to describe them one can use a line different equation with the application of Hook's law. This approach is justified because the used material and the dimensions of the disc meet the mentioned requirements. During the disc designing we must remember that not only cannot this disc deform itself but its too big elastic strain is not advisable.

5. REFERENCES

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