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DYNAMIC DEFORMATION AND FRACTURE OF THIN METAL RING SAMPLES UNDER MAGNETIC PULSE LOADING

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Abstract. This paper presents an analysis of the equations describing electromagnetic oscillations in coupled coil and ring circuits. Based on this analysis, an equation had been established that allows determining the ring current, which was calculated for a wide range of capacitor voltages. Two experimental methods for determination of the current and Ampere force in a ring sample, as well as the radial pressure on its internal surface and its circumferential stress were developed and implemented.

1. Introduction

This paper continues the research of H. Zhang and K. Ravi-Chandar [1, 2], as well as our continuation thereof [3,4], by applying it to wider range of deformation rates. The magnetic pulse method for deformation and fracture of thin metal ring samples that has been developed and tested as part of this study is based on the interaction of the currents in a coil and a thin metal ring placed coaxially around it (the Ampere's force law).

2. Analysis of the Equations of the Electromagnetic Oscillations in Coupled Coil and Ring Circuits

Figure 1 shows the loading circuit. This circuit is based on lumped capacitance (C) and inductance (L) elements. The capacity of the circuit's capacitor was 0.5 μF. The circuit's inductor was a five-turn coil with a diameter of 25 mm made of 1 mm copper wire.

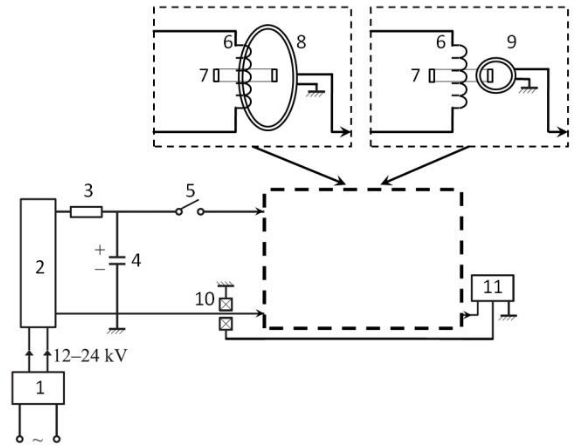


Fig. 1. Sample loading circuit:
1 - autotransformer, 2 - rectifier, 3 - charging resistor, 4 - capacitance, 5 - discharger, 6 - coil, 7 - ring, 8, 9 and 10 - Rogowski coil, 11 - oscilloscope.

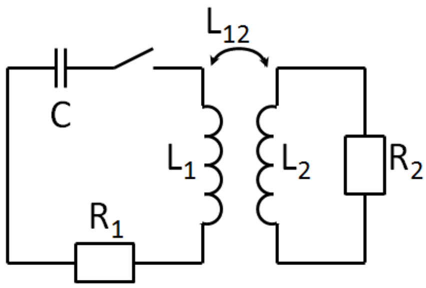


Fig. 2. Equivalent electric diagram.

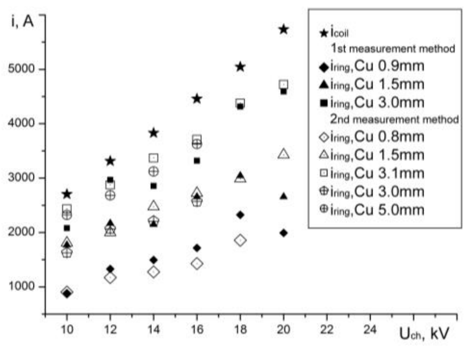


Fig. 3. Dependence of ring current on capacitor voltage for aluminum and copper rings of different widths.

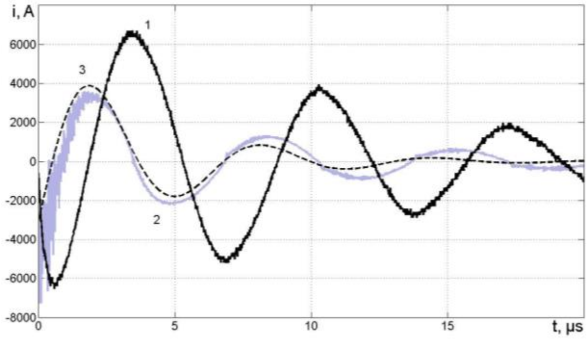


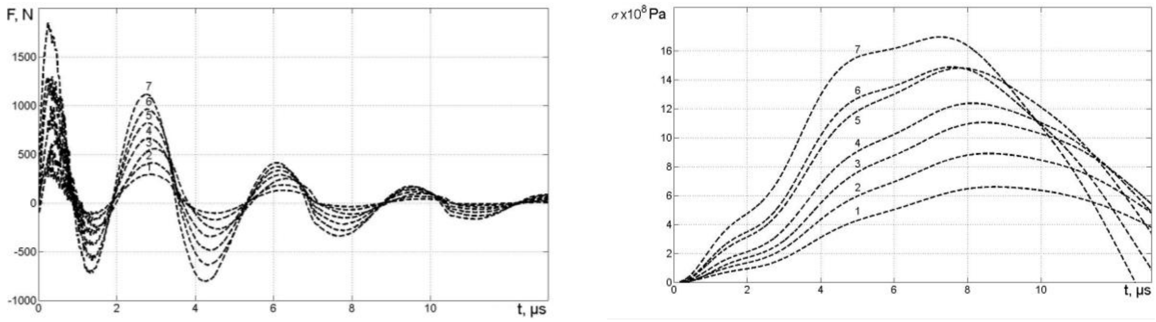
Fig. 4. Oscilloscope patterns for the coil current (1), as well as the measured (2) and calculated (3) ring current.

The distributed load acting on the inner surface of the ring $q(t) = F(t)/c$,wherein c - the width of the ring.

The circumferential stress in a ring was calculated using equation [5]:

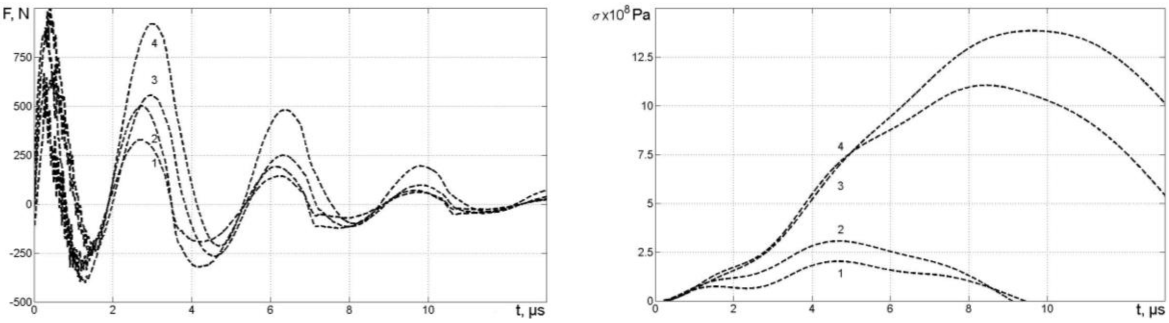
$$\sigma(t) = \frac{\partial\sigma}{\partial t}|_{t=0} \cdot \frac{1}{\omega} Sin\,\omega t + \omega \frac{R_0}{h} \int_0^t q(\tau)\, Sin\,\omega(t-\tau)d\tau. \qquad (7)$$

The values $F(t)$ and $\sigma(t)$ were calculated for aluminum and copper rings of different widths at different capacitor voltages, i.e. at different applied energies. As an example, Fig. 5 shows the dependence of the force (a) and circumferential stress (b) on the capacitor voltage for a 1.5 mm wide copper ring. The graphs in Fig. 6 show the values $F(t)$ and $\sigma(t)$ for different materials (aluminum and copper) for the capacitor energy E = 49 J.



a b

Fig. 5. Dependence of the force $F(t)$ (a) and circumferential stress $\sigma(t)$ (b) on the capacitor energy (1 — 25 J, 2 — 36 J, 3 — 49 J, 4 — 64 J, 5 — 81 J, 6 — 100 J, 7 — 121 J).



a b

Fig. 6. Force $F(t)$ (a) and circumferential stress $\sigma(t)$ (b) calculated for different ring materials and widths (1 — Al, 3.0 mm; 2 — Al, 5.0 mm; 3 — Cu, 1.5 mm; 4 — Cu, 3.1 mm).

The dependence graphs in Fig. 5 and 6 demonstrate the following: 1) Increasing the capacitor energy results in increasing amplitudes of F(t) and σ(t); 2) increasing the ring width (for both aluminum and copper rings) results in increasing F(t) and σ(t) values; 3) aluminum rings have lower amplitudes than copper ones. The latter two conclusions can be explained by the ring resistance decreasing with the increase of the ring width, and, as a consequence, the increase of the ring current. But most importantly that the circumferential stress σ in contrast to the force F is not pulsed. This is a fairly smooth function (see. Fig. 5b, 6b). This circumstance is due to the fact that the inertia of the ring smoothes fluctuations. Identified as a result of the calculations, these particular of ring samples dynamic deformation were previously found experimentally [5]. Analysis of calculated hoop stress changes allow to predict at which period of the current in the ring destruction is possible.

4. Summary

1. This paper presents an analysis of the equations describing electromagnetic oscillations in coupled coil and ring circuits, which allows calculating the ring current.
2. Two experimental methods for determining the ring current were developed and implemented.
3. A comparison of the measured and calculated ring current values was made.
4. Based on the coil and ring currents measured for a wide range of capacitor voltages, two different materials (aluminum and copper) and different ring widths, the dependences of the force acting on a ring and its circumferential stress on the capacitor energy were determined.
5. The obtained results allow assessing the deformation and strength parameters of the above two materials within a wide range of energy parameters.

References

[1] H. Zhang, K. Ravi-Chandar // *International Journal of Fracture* **142** (2006) 183.
[2] H. Zhang, K. Ravi-Chandar // *International Journal of Fracture* **150** (2008) 3.
[3] V.A. Morozov, Y.V. Petrov, A.A. Lukin, V.M. Katz, A.G. Udovik, S.A. Atroshenko, G.D. Fedorovsky // *Reports of the Academy of Sciences* **439(6)** (2011) 761.
[4] A.A. Lukin, N.F. Morozov, V.A. Morozov, Y.V. Petrov // *Procedia Materials Science* **3** (2014) 686.
[5] V.A. Morozov, Y.V. Petrov, A.A. Lukin, A.G. Udovik, S.A. Atroshenko, D.A. Gribanov // *Technical Physics* **84(9)** (2014) 78.