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Jason Baird
Missouri University of Science and Technology, jbaird@mst.edu

Paul Nicholas Worsey
Missouri University of Science and Technology, pworsey@mst.edu

Mark F. C. Schmidt

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EFFECTS OF DEFECTS ON ARMATURES WITHIN HELICAL FLUX-COMPRESSION GENERATORS*

J. Baird[ξ], P. N. Worsey, M. Schmidt
RMERC, University of Missouri - Rolla
Rolla, Missouri, USA

Abstract

Tubes of aluminum and copper filled with C-4 high-explosive were tested during this study of the effects of explosive flaws and voids, their sizes and locations, and of the effects of armature machining tolerances on the expansion characteristics of armatures within helical flux-compression generators.

Flaws and voids were introduced into the explosive fill of 6061-T6 aluminum armatures during assembly. The defects were located along the major axis of the fill, midway between the major axis and the explosive/armature interface, and at the interface. The resulting effects on armature expansion were recorded by high-speed framing camera, intensified charge-coupled display (ICCD) photography and by flash x-ray.

Outer and inner surface defects were introduced into OFHC copper and 6061-T6 aluminum armatures via machining. The resulting effects during armature expansion were recorded by framing camera and by ICCD.

I. INTRODUCTION

The authors are part of the Explosives Research Group located at the Rock Mechanics and Explosives Research Center (RMERC) of the University of Missouri-Rolla (UMR). In 1998, the Explosives Research Group, along with the Texas Tech University (TTU) Electrical Engineering Department's Pulsed Power Laboratory and researchers from the TTU Mechanical Engineering Department, formed the initial membership of a research consortium whose work has been described elsewhere [1].

During this research project, as a part of the process of looking for the causes of inefficiencies in flux-compression generators, void and defect testing was performed on armatures similar to those used for the research consortium's helical generator design. The cylinders were made of thick-walled aluminum or copper tubing, 3 mm thick and 15 cm long by 3.8 cm in diameter, filled with high explosive. During end-initiated, explosive-driven expansion tests of the cylinders in the detonation tank of the RMERC Explosives Laboratory, photographs were taken by either a high-speed Cordin 010-A framing camera or an ICCD camera system. Each cylinder was marked with index lines on 1 cm centers in ink on its outer surface. In a typical test, as the detonation progressed along the explosive charge, the cylinder would expand according to the progress of the detonation through it.

The armature is part of the electric circuit within the generator, and as the flux within the generator is being compressed, electric currents begin flowing on the outer surface of the armature in a circumferential direction due to the magnetic field orientation. The flow of these currents must not be disturbed. If their flow direction is altered, the magnetic field direction will be affected. If the current flow is retarded by features on the surface of the armature, theory says that arcing will form between the armature and the stator. The arcing will create a very hot plasma, and will cause the stator insulation to break down before the sliding contact reaches that location. Because the arcing causes the current flowing from the armature to the stator to jump ahead of the sliding contact, and the sliding contact is no longer part of the current path, compressed magnetic flux is trapped in the region between the sliding contact and the arc . The trapped flux is lost to the compression process, and is a source of inefficiency [2].

Other flux-compression researchers have told the authors that any armature surface finish flaw present prior to armature operation will most probably cause flux losses. They have also indicated that any void spaces or low density regions in the explosive would have a negative effect on the smoothness of armature expansion during generator operation. The purpose of this investigation was to photograph any such effects on armature expansion.

II. RESULTS AND DISCUSSION

The first tests were performed on copper and aluminum armatures with surface defects intentionally introduced by machining. Hand-packed C-4 (an RDX-based demolition explosive) was the fill in each test. The armatures in Fig. 1 were of 6061-T6 aluminum, one polished to a mirror surface and one intentionally machined to a very rough finish. Each photo was taken at approximately the same time in the expansion process. The top image is of the polished armature, the bottom is of the rough-surface armature. Note, it appears that the surface finish has little or no additional effect on an armature's expanded surface. The images in Fig. 1, 2, and 3 were 2 microsecond exposures.

The next set of photographs, Fig. 2 and 3, are of OFHC copper armatures, each broached along their lengths in four places, 90° apart. The broaching cuts were approximately 5

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[ξ] Member, IEEE

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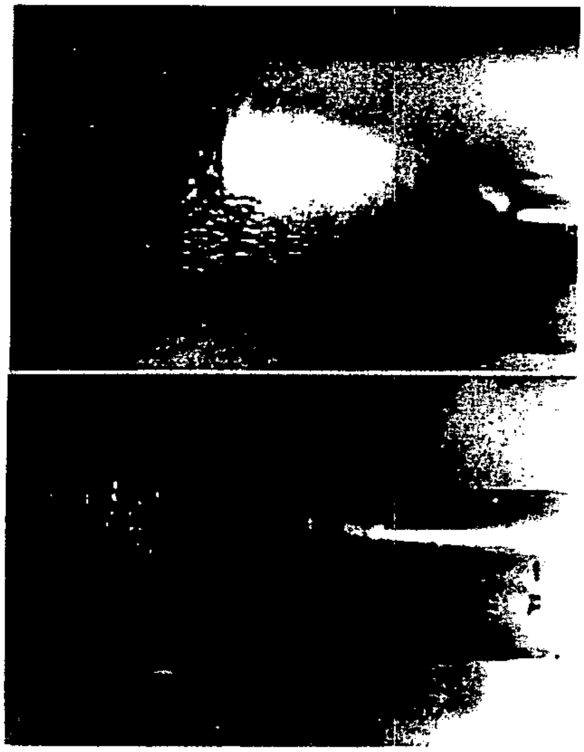

Figure 1. Armatures of different surface finishes.

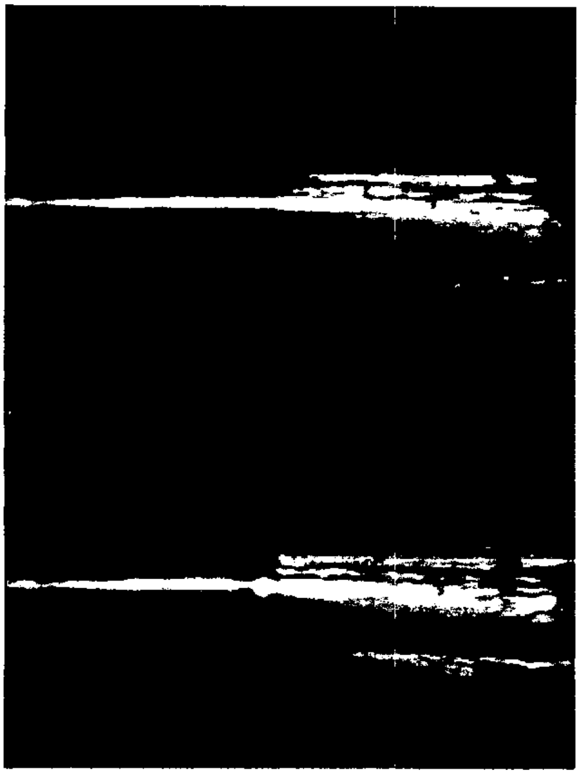

Figure 2. Copper armature with internal broach cuts

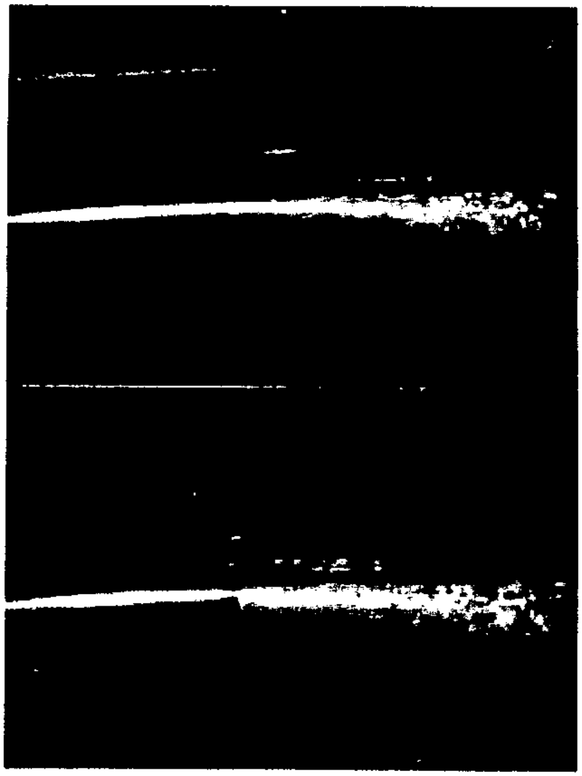

Figure 3. Copper armature with external broach cuts.

mm wide and 1.5 mm deep. The armature in Fig. 2 had internal cuts, and the one in Fig. 3, external cuts. Note the black gas (characteristic of RDX detonation products) escaping through the armature along the cuts. Such massive damage to armatures has a definite effect on how much they can expand before beginning to break apart.

The next set of tests was performed due to concerns of national lab researchers in advisory positions to this project. Their anxieties lay with the manner in which explosive was being loaded into the armatures. In the interest of simplicity, the explosive charges in the RMERC armature tests were all hand-packed. Small portions of C-4 were rolled into roughly spherical shapes by hand. As each ball of explosive was placed into an armature tube, it was rammed into place through the use of a sub-caliber wooden dowel. A slight twisting motion was imparted to the dowel by the loading personnel, in order to force the explosive to knit with previously-loaded portions of the charge. This technique, however, was thought to introduce cross-sectional voids and low-density regions within the explosive charge.

To ensure that cross-sectional voids were created in the explosive charges for this test series, the explosive was formed into discs of the same diameter as the inside diameter of the armature tubing. Each disc was approximately 2 cm thick, and each was placed into position within a charge by gentle pressure. The ICCD 60 nanosecond-exposure in Fig. 4 shows the "mold line" effect of such voids. The black "+" marks on the outer armature surface indicate the

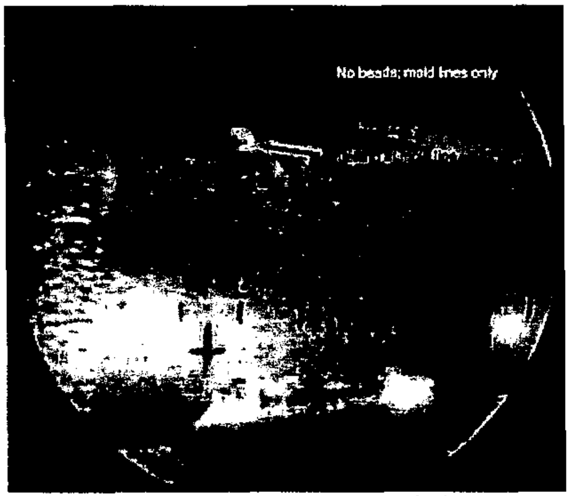

Figure 4. Aluminum armature with explosive cross-sectional defects.

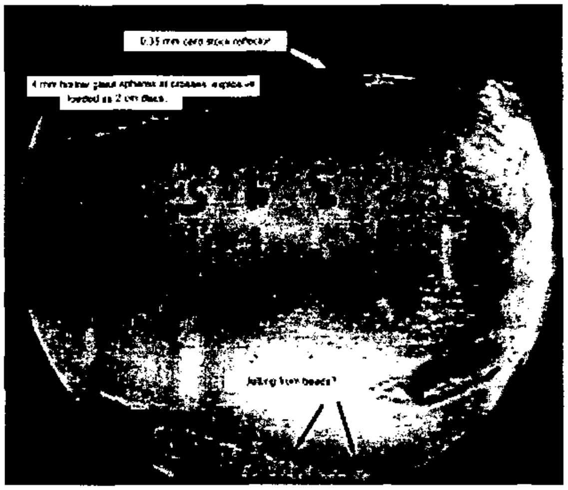

Figure 5. Aluminum armature with explosive charge cross-sectional and spherical void effects.

approximate positions where one disc ended and another began.

The armature shown in Fig. 5, also a 60 nanosecond ICCD image, was constructed in the same manner as the armature in Fig. 4, with one additional step. Spherical voids were introduced into the explosive charge by the insertion of hollow, 4 mm diameter glass beads into the charge along the explosive/tube interface. The beads (see Fig. 6) were placed between the explosive discs, along what was to be the bottom edge of the armature during testing.

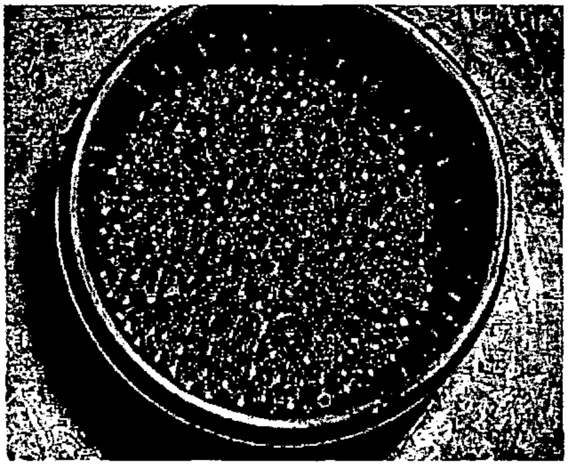

Figure 6. Hollow glass spheres used to create voids.

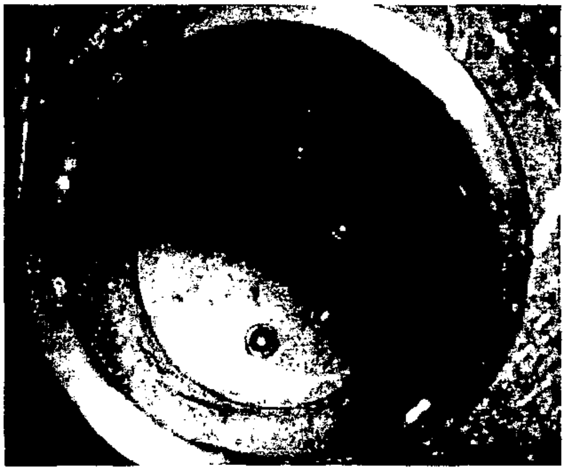

Figure 7. View of relative positions of spherical voids in each cross-section.

The luminous regions at the bottom of the armature in Fig. 5 appear to result either from detonation products beginning to escape through the armature, or from bulges in the armature surface. These regions correspond closely with bead locations. Note, also, that the "mold lines" are more definite farther along the armature surface in Fig. 5 than in Fig. 4. This could be due to the inherent inconsistencies in the sizes, shapes, and circumferential locations of cross-sectional voids produced by the explosive disc loading technique.

In order to evaluate the relative severity of armature surface irregularities caused by spherical voids/inclusions versus those caused by cross-sectional voids, another set of tests was performed. In this test series, the explosive charge was loaded using the ball and ram technique. At selected levels of explosive fill, after the ball of explosive had been rammed into place, the glass beads were placed into the explosive in the fashion shown in Fig. 7. The beads were pushed into small cavities created in the explosive, so they would stay in their relative positions when the next layer of explosive was rammed into place.

The ICCD image in Fig. 8 is of an armature test using the voids placed in this manner. The armature was positioned so that the outermost beads were at the top in the image. The "+" marks indicate the approximate positions of the cross-sections where the beads were included.

Figure 8. Aluminum armature, staggered void placement

Comparison of Fig. 8 and Fig. 4 shows that cross-sectional voids have a much greater impact on the quality of the expanding armature surface than spherical voids. The single indication of a disturbance of the armature surface in Fig. 8 is the luminous region at the top of the image, at about the 3 cm point. This region is possibly due to the bead at that approximate position. The remainder of the beads at that cross-section (beads not at the explosive/armature tube interface) had no discernible effect.

IV. SUMMARY

According to the test series reported herein:

- Minor armature surface irregularities remain during expansion, but do not affect the expansion process.
- Concerns about the hand-packed explosive loading technique are unfounded. Care by loading personnel to ensure that portions of the explosive charge knit with previously-loaded portions is sufficient to prevent armature surface irregularities during expansion.
- The only explosives void spaces which appear to have an effect on armature expansion are those which are located at or near the explosive/armature tube interface.

V. REFERENCES

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