FABRICATION OF SUPERCONDUCTING SPOKE CAVITY FOR LASER COMPTON SCATTERED PHOTON SOURCES

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Abstract

We are developing electron beam drivers used for laser Compton scattered (LCS) photon sources. For realizing a wide use of LCS X-ray and γ-ray sources in academic and industrial applications, we adopt the superconducting spoke cavity to electron beam drivers. The spoke cavity has advantages such as relative compactness in comparison with an elliptical cavity of the same frequency, robustness with respect to manufacturing inaccuracy due to its strong cell-to-cell coupling, the better packing in a linac to install couplers on outer conductor. On the other hand the spoke cavity has disadvantage of more complicated structure than an elliptical cavity. Though our proposal design for the photon source consists of the 325 MHz spoke cavities in 4K operation, we have begun to fabricate the half scale model of 650 MHz spoke cavity in order to accumulate our cavity production experience by effective utilization of our limited resources. In this paper, we present our fabrication status.

INTRODUCTION

We are developing laser Compton scattering (LCS) X-ray and gamma-ray sources combined with an energy-recovery linac (ERL) and a laser. The LCS X/γ-ray source is expected for application of non-destructive assay system of nuclear materials with nuclear resonance fluorescence [1], analysis of nano-structure, drug development, medical diagnostics, and so on. We are developing the superconducting spoke cavity for LCS photon sources [2]. Spoke cavities have many advantages such as shortening the distance between cavities, small frequency detune due to micro-phonics and easy adjustment of field distribution for strong cell coupling. We have optimized cavity shape with genetic algorithm [3] and started to fabricate the one-spoke cavity on the basis of die design simulation.

The spoke cavity for the compact X-ray source was originally designed at 325 MHz, which can be operated at 4 K. We have, however, recently changed our R&D plan to fabricate a 650 MHz cavity prior to 325 MHz one. This is because a 650 MHz cavity can be fabricated almost "in-house" at the KEK machine shop and suitable for accumulating our cavity production experience within limited resources. Once we learn the design and production process of spoke cavities at 650 MHz, we can easily apply our expertise to production of spoke cavities with difference frequencies.

PRESS FORMING OF SPOKE CAVITY

Optimization of the RF properties has caused the spoke shape somewhat complicated. Since one-step press forming with one die set will cause so large strain near the spoke center and spoke base to break sheets of material. In order to reduce the strain, press forming process is divided into three steps as shown in Fig. 1.

(i) The center die is set above the level of the die and the inner punch is forced downward to bend the sheet transversely with the die center.
(ii) Holding the sheet between the center die and the inner punch, the center die and the inner punch are forced downward at the same time to bend the sheet longitudinally with the die.
(iii) The outer punch is forced downward to form the half-spoke base.

To realize the above steps in a sequence of one slide action the press machine requires a die cushion to control the die center motion and the die set requires a spring functioning component such as a gas spring to control the inner punch action by the load.

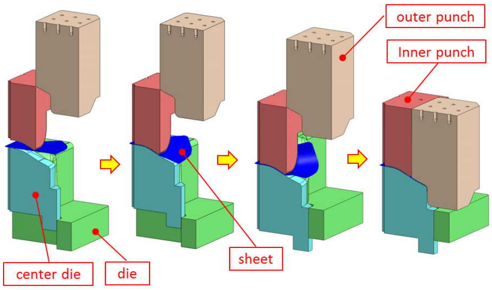

Figure 1: Press forming process for half-spoke. The views are divided in quarters.

FABRICATION OF DIE SET

As the frequency is double, the size of the cavity and the die set are half of the original 325 MHz design. The press forming simulation was performed with the dies and the punches scaled down from 325 MHz to 650 MHz. Comparing to the result of half-spoke press forming of 325 MHz and 650 MHz, there is no major difference as shown in Fig. 2.

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Since the size of die set becomes half, we planned at the beginning to use the press machine of AMADA SDE1522 in KEK, which specifications are shown in Table 1. Since the half size of the original 325MHz die set design exceeds the die height of the press machine, we have redesigned the die set by changing the type and number of the gas springs and reducing the thickness of the die set as thin as possible. Though the press machine changed to AIDA NC1-15 due to operator's schedule, this machine has similar specifications to AMADA SDE1522.

The components of the die set which contact with the sheet metals are made of extra super duralumin of A7075 and ANP79. The other components of the die set which support the whole structure are made of SS400. The assembled die set mounted to the press machine is shown in Fig. 3.

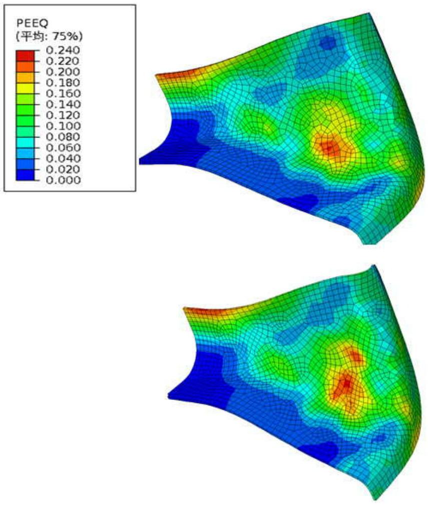

Figure 2: Calculated strain distribution by press forming of 325 MHz (top) and 650MHz (bottom) half-spoke.

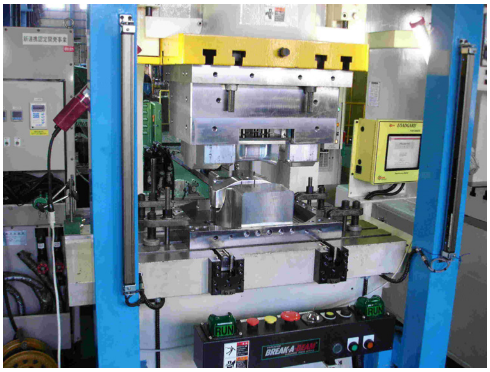

Figure 3: Assembled die set was mounted to press machine.

Table 1: Specifications of Press Machines

Press machine	AMADA SDE1522	AIDA NC1-15
Capacity of nominal force	1500 kN	1500 kN
Slide stroke	225 mm	200 mm
Die height	430 mm	400 mm
Capacity of die cushion	80 kN	100 kN
Die cushion stroke	80 mm	80 mm

PRESS FORMING TEST OF HALF-SPOKE

Press forming test was carried out to confirm the die set performance. The copper and aluminum plates of 1.0 mm, 1.5 mm and 2.5 mm thick were prepared. The result of the press forming test with annealed Cu plate of 1.5 mm thick is shown in Fig. 4 (left). There occurred wrinkles around the spoke side corner. These wrinkles also occurred with 1.0 mm thick plate and with annealed Al plate of 1.5 mm thick as shown in Fig. 4 (right). In order to investigate the cause of the wrinkles unannealed Al plates of 1.5mm thick were pressed changing the slide position of the press machine to 16 mm, 11 mm, 6 mm and 0 mm from bottom dead center. Figure 5 shows the side views of the press formed plates. The cracks were caused owing to the unannealed plates.

Though the plate should be dragged along the die smoothly with the slide moving downward, the plate was a little caught at the die corner between upper and inside surfaces in the test. Therefore the plate was bended more than expected and further deformation leading to wrinkles occurred with the slide moving further downward. The rubbed trace caused by being caught at the die corner can be observed at the side of the press formed plates of Fig. 5.

The large strain around the corner of the spoke due to this deformation can be observed in the structural analysis results calculated with simulation code "ABAQUS" as shown in Fig. 6. The simulation results also show the maximum strain changes according to the thickness.

Figure 7 shows the difference of deformation compared with the plates of 1.5 mm and 2.5 mm thick. In this press forming the slide was moved to the position where the minimum gap between the die and the inner punch became 2.5 mm. The plate of 2.5 mm thick has less deformation around the corner than that of 1.5 mm thick.

The strain distribution was measured with scribed circle test. In this measurement the array of 5 mm diameter circles was stamped on a plate before press forming and the lengths of two axes distorted by press forming were measured to estimate the principal strain. The stamped circles were transcribed to some pieces of transparent tape to measure lengths since the press formed surface is not flat. The measured results of side and base of the half-spoke are shown in Fig. 8. There are large strain regions at the center of the spoke side and at the edge of the half-spoke base. Figure 2 shows the large strain region of simulation result. Though the large strain area at the spoke side correspond to measured and calculated results, the magnitude of measured strain is larger than that of calculated. This could also result from being caught at the die corner.

The large strain area at the spoke base resulted from overlapping of the press forming steps by the inner punch and the outer punch. Since the die set was cut down to be mounted into narrow die height of the press machine, the initial position of the inner punch and the outer punch became closer than the original design. As the result the press forming by the outer punch began before the press forming by the inner punch finished. This caused large strain at the spoke base.

CONCLUSION

The die set for the half-spoke was fabricated and press forming tests were carried out with copper and aluminum plates to check the die set. The wrinkles were formed around the corner of half-spoke and these wrinkles seem to be related to the corner shape of die which prevents the plate from being dragged smoothly. We are planning to modify the die set and to use thicker plate for the next press forming test.

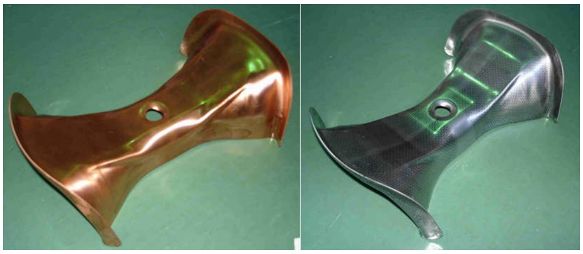

Figure 4: Press forming of half-spoke with 1.5 mm plates of copper (left) and aluminum (right).

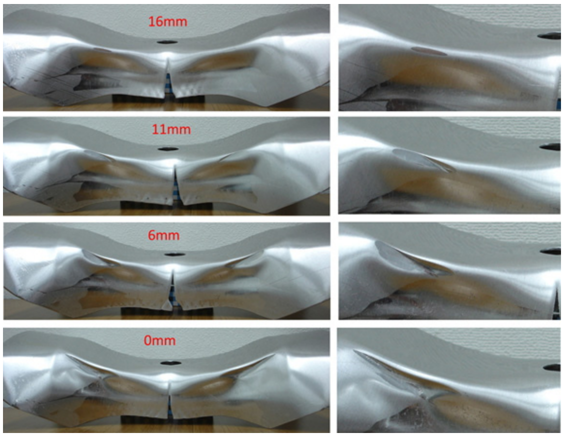

Figure 5: Press forming of unannealed aluminum plate by changing the slide position of 16 mm, 11 mm, 6 mm and 0 mm from bottom dead center.

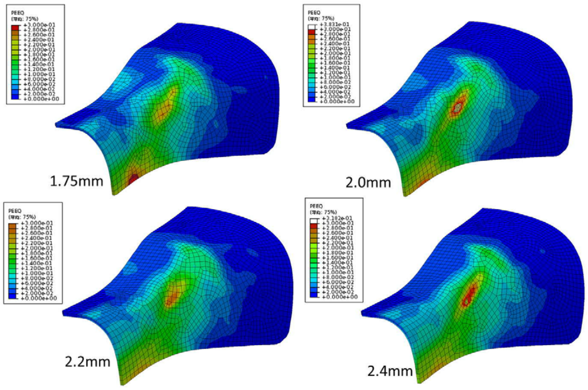

Figure 6: Calculated strain distributions of spoke with different thickness of plate.

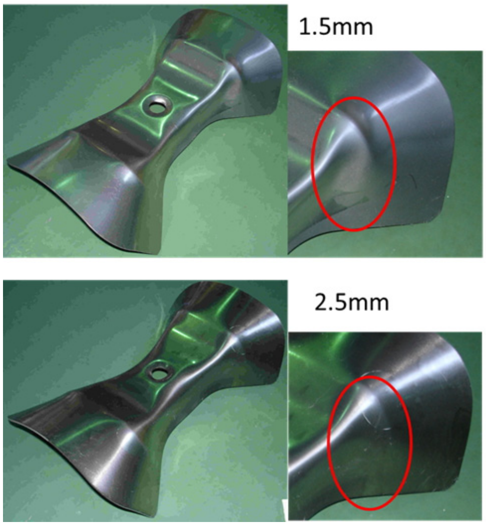

Figure 7: Press forming of aluminum plates of 1.5 mm and 2.5 mm thick.

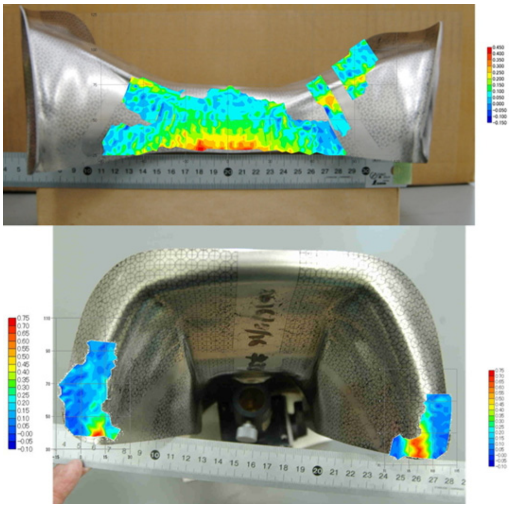

Figure 8: Measured strain distributions at the side (top) and the base (bottom) of half-spoke.

ACKNOWLEDGEMENT

This study is supported by Photon and Quantum Basic Research Coordinated Development Program of MEXT, Japan.

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