DESIGN AND DEVELOPMENT OF SUPERCONDUCTING SPOKE CAVITY FOR COMPACT PHOTON SOURCE

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Abstract

The spoke cavity is expected to have advantages for compact ERL accelerator for X/γ-ray source based on laser Compton scattering. We have been developing the spoke cavity under a research program of MEXT, Japan to establish the fabrication process. Since our designed shape of the spoke cavity is complicated due to optimization of the RF properties, we have been designing the mold including the process of press forming and the support parts for vacuum tolerance with the mechanical simulation. In this paper we present status of the spoke cavity fabrication.

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 have launched a 5-year research program since 2013 to develop 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 almost finished cavity shape optimization [3] and been making a study of mold design and mechanical design to fabricate the niobium one-spoke cavity.

PRESS FORMING OF SPOKE CAVITY

The spoke cavity is going to be fabricated with three kinds of parts divided as shown in Figure 1.
- (i) Spoke part
- (ii) End-plate part
- (iii) Tank part

The spoke is also divided into two half-spokes and a beam pipe. The half-spoke and the end-plate are made by press forming. The spoke base is bended into the same shape of the tank curve considering the connection to the tank.

Since the shape of the spoke is complicated, one-step press forming with one set of molds will cause so large strain to break the sheet. The strain distribution of half-spoke formed in one-step is shown in Figure 2 (top). This was calculated with 3D structural analysis software

Abaqus. There were some areas of large strain near the spoke center and spoke base. In order to reduce the strain, forming process is divided into three steps as shown in Figure 3.
- (i) The center die is set above the level of the die and the inner punch is forced downward to bend the sheet crossways 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 longways with the die.
- (iii) The outer punch is forced downward to form the half-spoke base.

The simulation result of the strain distribution of half-spoke through above process is shown in Figure 2 (bottom). Though there still remains large strain area, the most of strain was reduced to less than 0.3 and this result is estimated to avoid breaking the sheet during the press forming process.
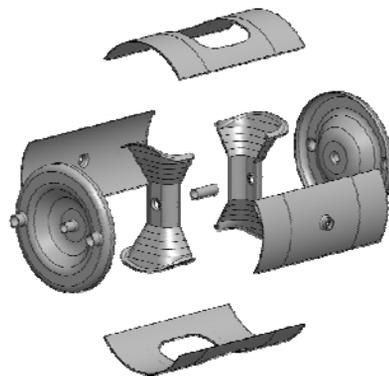

Figure 1: Exploded schematic of one-spoke cavity.

SPOKE CAVITY SUPPORTS

Mechanical analysis has been performed to control the mechanical deformations caused by the external load such as vacuum load and/or liquid/gas helium pressure. If the stress exceeds the elastic deformation to cause plastic deformation, the deformation will be accumulated to result in the frequency shift every time the external force is loaded. Figure 4 (top) shows the stress distribution when the cavity is externally loaded to 1 bar. The gray areas indicate the large stress to cause plastic deformation. The large stress occurs at the spoke base and the end-plate.

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The annular rib and radial ribs as shown in Figure 5 are adopted to stiffen the end-plate. To simplify the welding to the end-plate, the radial ribs are connected only to the annular rib and beam pipe, while the annular rib is connected to the end-plate.

Figure 6 shows the stress distributions with the various radii of the annular ribs. The large radius of the annular rib decreases the stress of the end-plate center and increases the beam pipe stress. The radius of about 110mm is suitable to reduce the both stress of the end-plate and beam pipe.

The mechanical analysis was also performed for the spoke base supports of three types as shown in Figure 7.

(a) A support plate is attached near the spoke base along the tank curve. (Figure 7 a)

(b) A support bar is attached along the spoke corner. (Figure 7 b)

(c) A support plate is attached at the spoke base curve. (Figure 7 c)

The simulation results of stress distribution indicate that the type (a) cannot reduce the stress of the spoke base and that type (b) and (c) can reduce. The final design will be determined with consideration of welding process.

The stress distribution of the spoke cavity with the supports is shown in Figure 4 (bottom). Since the ports are attached at the end-plates and the tank side, the mechanical analysis is going to be performed with the total design model.

FREQUENCY CHANGE

The spoke cavity for the compact X-ray source was originally designed at 325 MHz, which can be operated at 4K. We have, however, recently changed our R&D plan to fabricate a 650 MHz cavity prior to 325 MHz ones. 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
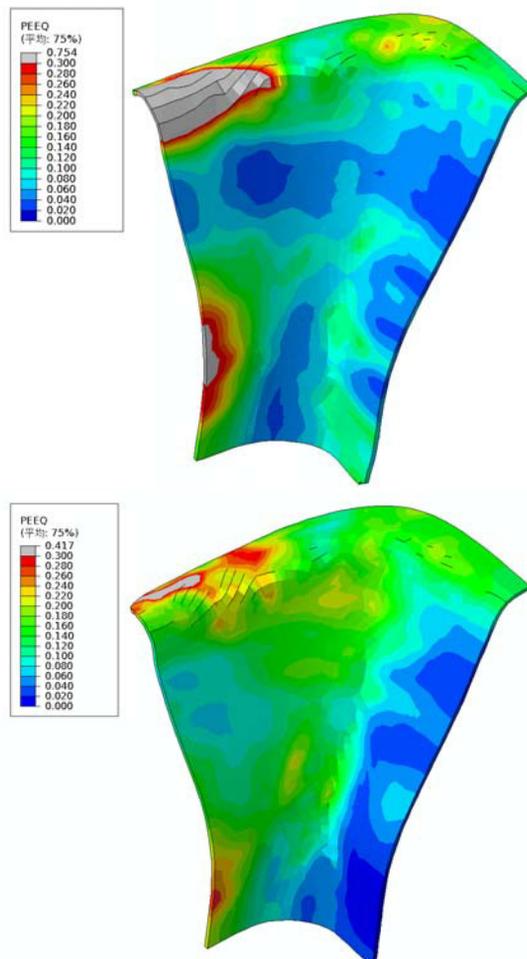

Figure 2: Calculated strain distribution of the 325 MHz half-spoke formed in one step (top) and in three steps (bottom).

production process of spoke cavities at 650 MHz, we can easily apply our expertise to production of spoke cavities with difference frequencies.

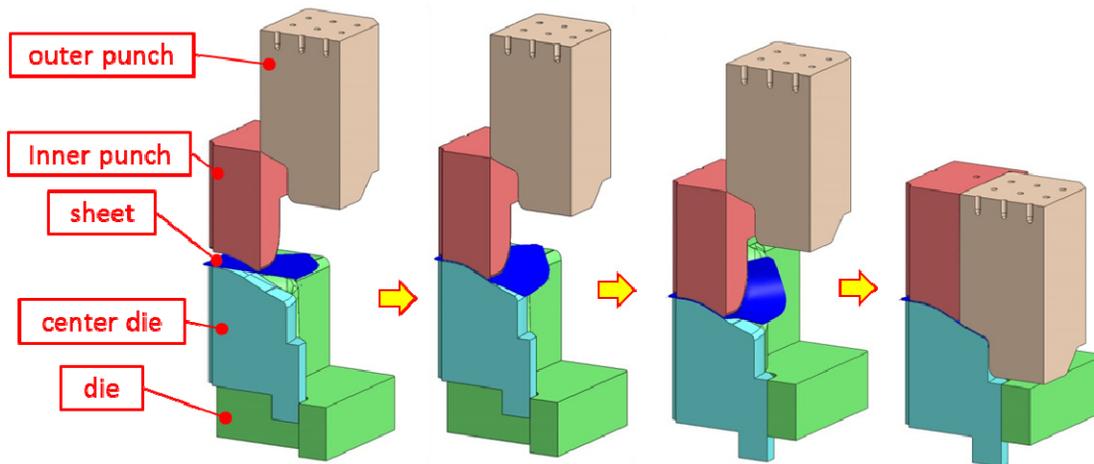As the frequency is double, the size of the cavity is half.

Figure 3: Procedures of press forming process for half-spoke. The views are divided in quarters.

Though the thickness of the sheet becomes 1.75 mm by scaling down to half size, it is preferable to use the thicker sheet more than 2 mm. The press forming simulation was performed with the dies and the punches scaled down from 325 MHz to 650 MHz and the thicker sheet than the half. The surfaces of punches were abraded according to the thickness of the sheets. Figure 8 shows the result of strain distribution of half-spoke using the sheet of 2.4mm thick. Comparing to the result of 325 MHz half-spoke in Figure 2 (bottom), there is no major difference.

CONCLUSION

The press forming design was performed to reduce the strain by adopting the three-step press forming for the half-spoke to avoid breaking the sheet. The spoke cavity supports were also designed to stiffen the end-plates and the spoke bases against the external load.

We are going to make molds and to perform the press forming test in order to fabricate the 650 MHz one-spoke cavity.
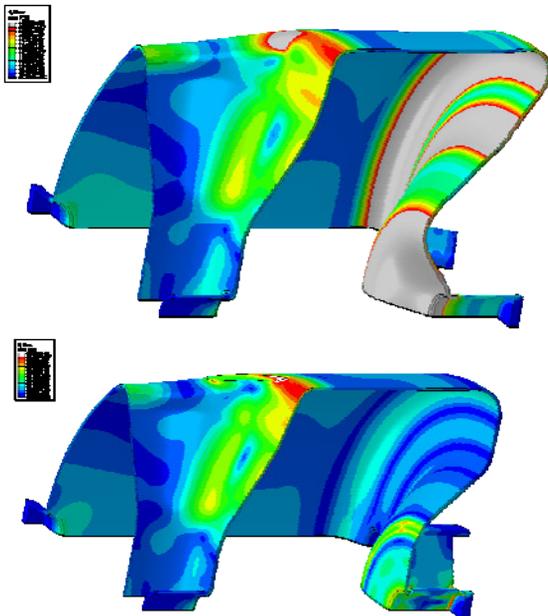

Figure 4: Calculated stress distribution of 325 MHz one-spoke cavity without supports (top) and with supports (bottom).
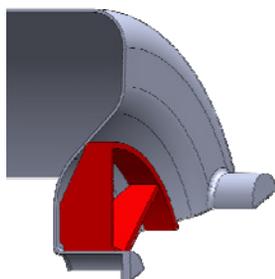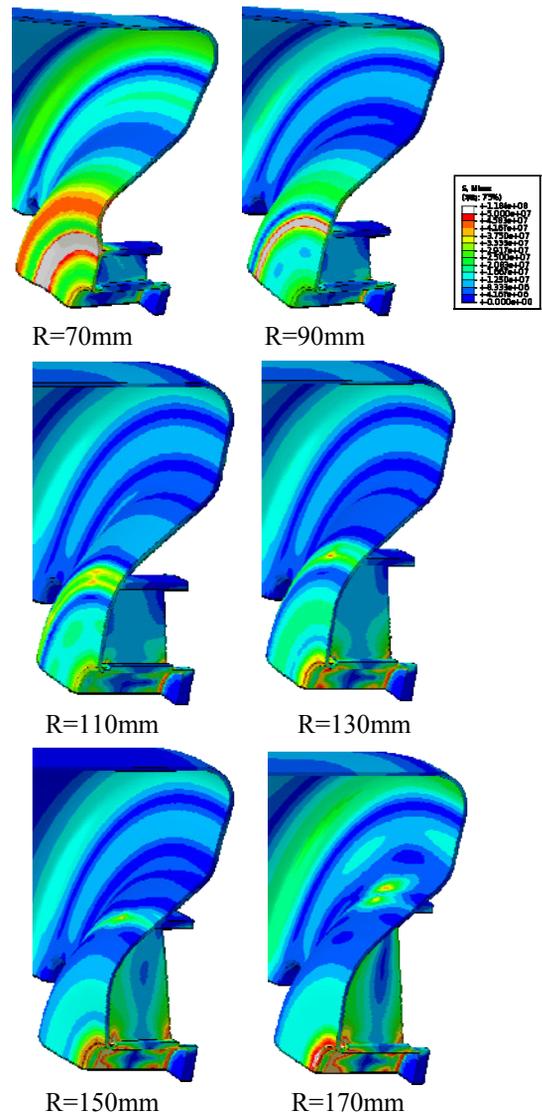

Figure 5: View of annular rib and radial ribs.

R=70mm   R=90mm

R=110mm   R=130mm

R=150mm   R=170mm

Figure 6: Calculated stress distribution of end-plate with various radii of annular rib.

ACKNOWLEDGEMENT

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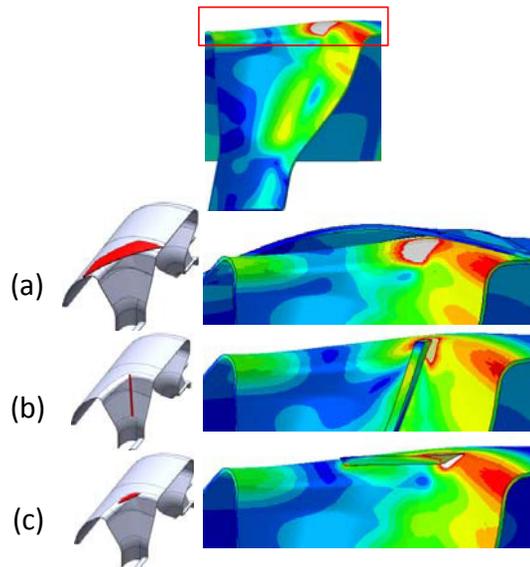
Figure 7: Calculated stress distribution at the end of spoke with different types of supports. The right figures of (a)-(c) are extension of the red square part of the top figure.
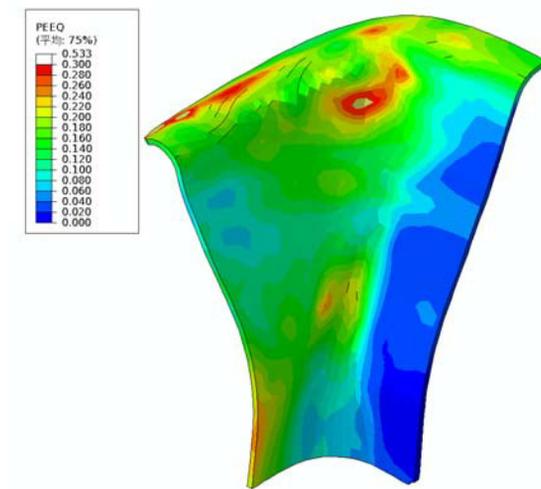

Figure 8: Calculated strain distribution of the 650 MHz half-spoke formed in three steps with 2.4 mm thickness sheet.