NON-DESTRUCTIVE EVALUATION OF CLOSE DIE FORGED MAIN BODY OF PRIMARY SYSTEM VALVES

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ABSTRACT

The main body of primary system valves discussed in this paper is made of stabilized austenitic stainless steel and are of intricate shapes & sizes. These bodies are produced through close die forging route and are manufactured first time in Indian forging shops. Finished forgings produced through three stage close die forging process are subjected to comprehensive quality assurance plan at each stage of manufacturing. The stages of manufacturing are raw material processing, close die forging, heat treatment, material testing, machining, hydro test & dimensional measurements.

Non-destructive examinations (NDE) required at various stages of manufacturing are mentioned in this paper. Main NDE examination is ultrasonic examination and is generally performed on close die forging in two stages i.e. one in solid condition & other in hollow condition (after drilling central holes) to satisfy code requirements. The examination at former stage is straight beam examination of solid product whereas at later stage it is angle beam examination of a hollow product. The quality of the forgings is ultrasonically evaluated with stringent acceptance requirements for straight & angle beam scanning. Reference reflectors are flat bottom holes (3 mm or less) and V notches (3% of finished thickness). This paper describe the procedure that envisages both stage ultrasonic examinations performed after heat treatment of forged blocks & ensures ultrasonic quality requirements of forged blocks as well as finished body.

Some of the challenges are, ultrasonic examination of stainless steel forgings with higher sensitivity, maximum coverage of metal volume with intricate shape, combining of ultrasonic examination stages to improve productivity. The main task is to establish, demonstrate and train vendor manpower to conduct ultrasonic examination in line with specification requirements. Major advantage of the procedure was performance of two stage ultrasonic examination (i.e. solid & hollow product) in single stage, which is completed before shipment from forging shop. It eliminates one machine setup resulting in reduced machining time without compromising the quality & avoids conflicts with vendors.

Keywords: Close die forging, Valve body, Ultrasonic Examination, Reference Bock, Straight Beam Scanning, Angle Beam Scanning, Dead Zone, Grain Size, Probe Frequency, Attenuation.

1. INTRODUCTION

Primary system valves discussed in this paper are non standard valves of various types and sizes. The main body of valves is made of stabilized austenitic stainless steel Type321. Valves bodies are of intricate shape to meet functional requirements as shown in figure1. Rolled/Forged bars are used as raw material for manufacturing of the close die forgings. The close die forgings are manufactured through three forging stages like blocker, semi forging & finished forging depending on size, shape & weight of the valve body. Subsequently, solution annealing of close die forgings performed for resistance to inter granular corrosion. Close die forgings are subjected to mechanical test, corrosion test and metallurgical tests. Valves body is subjected to non-destructive examination after forgings satisfied specified mechanical, corrosion and metallurgical properties. Non-destructive examinations such as liquid penetrant examination & ultrasonic examination are performed at various stage of manufacturing. Close die are supplied to valve manufacturing shop after satisfactory inspection and testing for further operations like machining, welding,
assembly, inspection & testing as per approved quality assurance plan. These close die forgings are manufactured first time by the industries involved, due to this it was Mandatory to augment the existing ultrasonic examination infrastructure, establish & demonstrate the examination procedure and impart training to qualified personnel for satisfactory examination. It was essential to utilize commercially available hardware for examination of close die forgings, as the objective is to perform examination without spending time in developing/arranging appropriate hardware, which may hamper the production schedule.

2. NON DESTRUCTIVE EXAMINATION (NDE) FOR VALVES BODY

NDE procedures formulated in line with requirement of ASME Sec III NB and ASME SEC V. NDE are performed after solution annealing at important stages to detect surface & internal discontinuities in the forged and machined body. Generally ultrasonic examination is performed to detect internal discontinuities where as liquid penetrant examination is performed to detect surface discontinuities.

Liquid penetrant examination is performed at two stages. The first stage is liquid penetrant examination of solid close die forgings after solution annealing. It is performed to detect surface discontinuities like laps and surface cracks. Second stage is after final machining of the valve body. Examination at this stage is performed to detect discontinuities surfaced due to machining and it confirms continuity of the internal & outer surfaces of the valves body. Liquid penetrant examination procedure formulated in line with requirement of ASME Sec V article 6. Acceptance criteria followed is as recommended in the NB 2546.

ASME Sec III NB boiler and pressure vessel code recommends straight beam ultrasonic examination of solid forgings in two perpendicular directions and angle beam examination of hollow products [1]. Angle beam circumferential and axial scanning is performed in two opposite directions. Generally solid close die forging is converted into hollow body through machining as shown in Fig. 2 & 3 for these scanning. Solid close die forging are of the sizes varying from 25 to 215 mm diameter and 150 to 430 mm axial distance. The finished thickness of the valve body varying from 6 to 20mm. Therefore, it needs to be evaluated for solid as well as hollow product as per the code requirements. Straight beam scanning is performed using flat bottom holes as reference reflector. The size of the flat bottom hole is governed by the forging dimension under examination. In solid close die forging the dimensions examined are diameter of the valve body in radial scanning and length of the body for axial scanning. Angle beam scanning is performed using V or square notch as reference reflector. The notch depth is governed by wall thickness of the valve body after machining. Since thickness is much less than the solid forging dimensions the sensitivity of examination of hollow body is much higher than solid close die forging. In General ultrasonic examination is performed at two stages i.e. after solution annealing at the forge shop and subsequently after machining of flow bores without finish machining of body as outer profile of body may obstruct probe movement and restricts full examination of forging volume. Machining operation is interrupted after flow bore machining & prior to finish machining of body for ultrasonic examination. Two machine set up are required to facilitate ultrasonic examination. The ultrasonic procedure described here combines ultrasonic examinations required at two stages mentioned above in one stage that is of solid forgings after solution annealing. Implementation of the procedure improves productivity by facilitating uninterrupted machining of solid close die forging into finished valves body. This procedure facilitate valve body machining in single set up that results in better dimensional accuracy.

3. ULTRASONIC EXAMINATION REQUIREMENTS

The valve bodies manufactured from close die forging are for primary system of nuclear power plant. In view of application the examination requirements are stringent in comparison to other applications. Reference reflector specified for straight and angle beam scanning are described below.

3.1 Reference reflectors for ultrasonic examination

FBH for different forging diameters/metal paths and notch dimensions for angle beam scanning are mentioned in table 1 & 2 respectively.

Table 1 : FBH sizes for straight beam scanning

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Forging diameter/Metal path</th>
<th>Recording based on FBH dia</th>
<th>Acceptance based on FBH dia</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dia 10 - 40 mm</td>
<td>Dia 2 mm</td>
<td>Dai 2 mm</td>
</tr>
<tr>
<td>2.</td>
<td>Dia 41 – 75 mm</td>
<td>Dia 3 mm</td>
<td>Dai 3 mm</td>
</tr>
<tr>
<td>3.</td>
<td>Dia 76 mm and above</td>
<td>Dai 3 mm</td>
<td>Dia 5 mm</td>
</tr>
</tbody>
</table>

Table 2 : Notch dimensions for angle beam scanning

| Sr. No. | Notch shape | Notch depth | Notch width |
|---------|-------------|-------------|-------------|-------------|
Notch length

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Rectangular notch 3% of finished body thickness Up to two times depth 30 mm max</td>
</tr>
<tr>
<td>2.</td>
<td>60 degree V notch 3% of finished body thickness - 30 mm max</td>
</tr>
</tbody>
</table>

### 3.2 Recording and acceptance criteria

Specified recording and acceptance criteria for ultrasonic examination are described below.

- **3.2.1 Recording criteria for straight beam scanning** is as mentioned in the table.

- **3.2.2 Any indication equal to or above 50% of reference** is recordable for angle beam scanning.

- **3.2.3 Indication length shall be measured with 6 db drop** method.

- **3.2.4 Any indication exceeding reference reflector echo height mentioned in tables above is unacceptable.**

- **3.2.5 Recordable indication having length greater than 30 mm is not permissible.**

- **3.2.6 Loss of back wall echo in excess of 50% or more of the original back wall echo is not permissible unless it is proved that the loss is not because of discontinuities.**

### 4. ULTRASONIC EXAMINATION PROCEDURE FORMULATION

The procedure comprising paragraphs titled scope, reference document, personnel qualification, machine requirements, probe requirements, reference block, scanning directions, indication interpretation & evaluation and reporting etc generated. Each paragraph is elaborated in the procedure. In view of variety of body sizes, it is considered essential to generate technique sheet for examination of each close die forging for each valve body. The procedure indicates the general guidelines for the examination whereas technique sheets covered further details for examination of specific close die forging for the body. All the technique sheets are approved by qualified level III personnel prior to use.

Most critical elements for foolproof examination are probe selection, reference blocks making, technique sheets preparation. Reasoning behind identification of these elements as critical and means devised to address these critical elements of the procedure are elaborated in subsequent paragraphs.

### 5. PROBE SELECTION

Critical factors need to be considered for probe selection is probe size, probe frequency, dead zone and beam angle. Some of the close die forgings are of smaller size (dia 25 mm), it is favorable to deploy miniature probes to facilitate better contact at time of scanning or use probe shoes to improve the probe contact with forging surface.

Probe frequency selection is important while scanning austenitic stainless steels. It is observed that 2-1 MHz probes are most suitable for scanning larger distances (about 200 mm) as ultrasound beam scattering & attenuation is less for low frequency probes. Therefore, it is desirable to utilize low frequency probes instead of high frequency probes. Low frequency straight beam probes are specified for scanning with larger beam paths. Low frequency probes have large dead zone, which occupies approximately 20mm surface volume for 2 MHz probe. Dead zone is not a concern while performing radial scanning on diameter larger than 40 mm. In case of smaller diameter application dual crystal probes is mandatory for full ultrasonic examination coverage.

Angle beam scanning is recommended with high frequency (4 MHz and above) probes as smaller thickness are to be scanned. Another added advantage of deployment of high frequency probe is lower dead zone [2]. Lower dead zone minimizes the un-scanned region adjacent to scanning surface. Dead zone of 5 mm observed with 45 degree 4 MHz probe. It is decided to deploy 4 MHz or higher frequency angle beam probe for circumferential & axial beam scanning.

All the close die forgings need to be examined with angle beam probe in circumferential directions. In order to maximize examination volume in circumferential scanning it is essential to deploy the smallest probe angle. In view of this, use of 38 degree probe required instead of 45 degree probe. Internal diameter greater than 0.7 times outer diameter can be fully scanned circumferentially with 45 degree probe. Circumferential scanning shall be performed with 38 degree probe for internal diameter smaller than limit mentioned above. Internal diameter up to 0.62 times of outer diameter can be fully scanned with the use of 38 degree probe. The core region having diameter less than 0.62 remains un-scanned as probe angle lower than 38 degree beam angle cannot be manufactured with shear wave.

Austenitic stainless steel poses problem in ultrasonic examination due to ultrasonic beam scattering & subsequent attenuation. Attenuation makes it impossible to examine large forging cross sections as beam could not penetrate to larger beam paths. Scattering & attenuation occur in the forgings with coarse grains. Coarse grains also result in larger grass echo (low signal to noise ratio) & spurious indication on the CRT screen due to reflection of ultrasonic beam from grain boundaries. Grass makes it impossible to detect indication echoes up to its height at larger beam paths. Forging temperature and solution annealing soaking time & temperature are critical parameters need to be kept on lower side to prevent grain coarsening. It is observed that ASTM grain size 0 is large enough to generate spurious indications reaching recordable levels. ASTM grain size 4 or finer is desirable for austenitic stainless steel size up to 300 mm.

### 6. REFERENCE BLOCKS

Ideally reference block should be from same heat and batch to match acoustic properties. Dimensions of the reference block should also be similar to forging being examined. When large varieties of forgings are to be examined, it is almost impractical
Important factors like minimum three points DAC and two point DAC are considered for straight beam scanning & angle beam scanning respectively while preparing the technique sheet. Full coverage of finished body material in each scanning is emphasized while selecting scanning directions and probe angle. Probe angle for circumferential scanning is suggested on the basis of ratio of internal diameter with outer diameter of the finished forging to scan as much as possible body metal volume. In case core region material remains un-scanned in circumferential scanning even after deploying 38 degree probe, un-scanned region identified in technique sheet.

8. SCANNING DIRECTIONS

All the solid forgings are scanned in radial as well as axial direction using straight beam. In addition forgings are scanned in axial and circumferential direction using angle beam. The angle beam circumferential and axial scanning is performed in to opposite directions.

Forging volume full coverage & dead zone are not an issue in straight beam radial & angle beam scanning. Calibration for angle beam scanning is performed on hollow calibration block, the ultrasonic waves are not reflected in actual scanning from internal dia as forging are solid. Therefore, dead zone is an issue for axial angle beam scanning of solid forgings.

The area of interest is the thickness of finished body as core material is to be machined out. Small outer surface volume (3.5 mm for 5mm dead zone) remains un-scanned due to dead zone in angle beam axial scanning. Therefore, 4 Mhz or higher frequency angle beam probe is utilized to minimize dead zone for angle beam axial scanning. Finished body inner surface volume remains un-scanned in circumferential scanning even after deploying 38 degree probe and central core region machining for finished body having internal diameter smaller than 0.62 times outer diameter.

9. CHALLENGES ENCOUNTERED

The objective of procedure making is to perform examination first time right without diluting the requirements. Major
CONCLUSION

The procedure facilitated forging ultrasonic examination at early stage of manufacturing and eliminated at least one machining set up. This resulted in greater dimensional control of finished body which is essential for the valves. Ultrasonic examination at early stage i.e. close die forging eliminated surfacing of discontinuities at later stage of body machining and subsequent conflict with close die forging manufacturer. Two thousand close die forgings for valve body are examined satisfactorily using the procedure.

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