

## **Experience in Manufacturing of Sleeves for Diverse & Safety Rod Drive Mechanism (DSRDM) of PFBR**

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### **Abstract**

This paper narrates the challenges faced and methodology implemented during manufacturing of Sleeves for Diverse - Safety Rod Drive Mechanism (DSRDM) in PFBR. Totally, 3 Nos. of Sleeves (250NB, Sch.40 x 4371mm long), manufactured, inspected, leak tested, surface treated and installed. The sleeve consist of top flange, top piece, middle piece, bottom piece, conical shell and cylindrical pins. It is a very slender component and straightness requirement is 0.50 mm per 1m. It shall be less than 2.18 mm for overall length of the sleeve assembly. To achieve the specified geometrical tolerances, design of the assembly made in such a way that top and middle pieces connected using guided butt joint with 12 nos. of cylindrical pins as load bearing members and circular seam weld joint for ensuring leak tightness. Similarly, the middle and bottom pieces were also connected using guided butt joint combination of pin joints with seal weld. This methodology of joining has minimized the weld distortion considerably and contributed for achieving the specified straightness. Also, during manufacturing, weld distortion was controlled using low heat input and sequence weld technique. Quality Assurance Plan (QAP) prepared and used during course of manufacturing. The material of construction is austenitic stainless steel grade 316L. Since, the sleeves used in the nuclear industry, the raw material qualification, welding procedure specification (WPS), procedure qualification record (PQR) and welder performance qualification (WPQ) record are mandatory requirements as per the nuclear standards. The raw materials are qualified as per ASTM A 240 and ASTM A 312 for plates and pipes respectively. The welding consumable ER 308L qualified as per ASME Section –II part-C. Welding procedure and welder qualifications carried out as per ASME Section-IX for gas tungsten arc welding (GTAW) process in 1G position. The raw materials (80, 40 mm thickness plates) were cut to the required sizes (with machining allowances) using CNC abrasive water jet cutting machine. Top Flange (OD 437 mm, ID 290 mm) machined from 40 mm thick plate. 12 tapped holes (M12 x 18 deep) and 12 counter bore holes on equip-spaced at pitch circle diameter (PCD) 407 mm. Top piece (OD 290mm, Length 2058mm) consisting of two parts, cylindrical shell of 290 mm outer diameter was rolled from 5 mm thick plate and long seam welded. 80mm thick, plate used to machine flange for connecting top piece and middle piece. All the machined parts assembled, aligned, match drilling made. The precisely machined cylindrical pins were inserted and 1 mm size seal welded followed by liquid penetrant inspection. Preparatory works viz. calibration of pressure gauges, piping with valves fittings, end connecting flanges with gaskets kept ready and 24 hours pressure hold test at 10mbar (g) conducted individually using nitrogen gas and observed no pressure drop.

Key words: GTAW process, pin joints, seal welds, liquid penetrant inspection ,pressure drop and pressure hold test

## 1.0 Introduction

The Diverse and Safety Rod Drive Mechanism (DSRDM) sleeves are essential components in PFBR, designed to house and protect critical drive assemblies. Their fabrication demands high precision, structural integrity, and adherence to stringent nuclear standards. Given their slender geometry and large length, welding plays a vital role in achieving dimensional accuracy, geometrical tolerance and mechanical strength.

The manufacturing process encompasses several critical stages, including the identification and qualification of the material (AISI 316L) to ensure its suitability, precise cutting of the raw material, and high-precision machining. Additionally, it involves forming the components to the required shapes and dimensions, followed by the assembly of these components. The final assembly process includes gas tungsten arc welding, which ensures strong and reliable joints. Throughout the entire manufacturing process, stringent geometrical controls are applied to maintain the out-of-roundness and straightness of the components within specified tolerance limits, ensuring the structural integrity and proper function of the storage containers.

Gas Tungsten Arc Welding (GTAW) was employed for all major joints due to its suitability for stainless steels and its ability to control heat input and distortion. Dedicated Welding Procedure Specifications (WPS) and Procedure Qualification Records (PQR) were developed in compliance with nuclear fabrication codes. Multiple welding challenges—such as distortion control, seal weld accuracy and maintaining straightness—were addressed through careful planning, fixture, and quality control.

This paper highlights the welding-centric approach adopted for the successful fabrication and of DSRDM sleeves, with an emphasis on process control, testing, and inspection techniques that ensured reliable and defect-free assemblies.

## 2.0 Description of DSRDM Sleeves

### 2.1 Overview -DSRDM

The overall size of sleeve for DSRDM is outer diameter 437mm and 437mm. The DSRDM assembly consists of a top flange, a top piece with flange, a tapered middle piece, a bottom piece, and a conical shell.

## 2.2 Identification and Qualification of the Raw Materials

The first stage of inspection was material identification which included verification of MTC (Material Test Certificates) supplied by the manufacturer of plates. The plates were checked for mill under-tolerance as per ASME section VIII div – I. This plate material was tested as per ASTM A-262 Practice A & E (IGC tests). Only after all the material test certificates were obtained and ascertained, the manufacturing of these vessels were initiated. All the plates were subjected to 100% ultrasonic testing with 10% overlap for any sub-surface defects like laminations, porosities etc.

The DSRDM sleeves were fabricated from AISI 316L to stainless steel, selected for its superior corrosion resistance—particularly against pitting and crevice corrosion due to its 2–3% molybdenum content—and its low carbon content, which enhances weldability. SS 316L was used for non-critical components like the top flange and alignment pins, offering adequate corrosion resistance, good machinability, and cost-effectiveness. Both materials, part of the austenitic stainless steel family, were rigorously tested to meet PFBR nuclear standards. AISI 316L was preferred for sleeves to ensure long-term performance in demanding reactor environments.

Component	Material
DSRDM Sleeves	AISI 316L
Top Flange & Pins	AISI 316L
Cylindrical Pins	AISI 316L (Ø8p6)

Table 1: Material of Construction

Element	SS 304L	AISI 316L
Carbon (C)	0.065	0.027
Manganese (Mn)	1.50	1.50
Silicon (Si)	0.70	0.74
Chromium (Cr)	20	18.0
Nickel (Ni)	9	12
Molybdenum (Mo)	—	2.5
Iron (Fe)	Balance	Balance

Table 2: Chemical Composition (% by weight)

### 2.2.1 Key Differences

**Molybdenum (Mo):** 316L contains Mo (2–3%), which enhances **corrosion resistance**, especially against chlorides (saltwater, chemicals) and high temperature creep strength.

**Carbon Content:** 316L has **lower carbon** than 316, making it better for **welding** and reducing risk of carbide precipitation.

**Corrosion Resistance:** 316L > 304, especially in harsh environments.

**Cost:** 316L is typically **more expensive** due to the added Mo.

## 2.3 Fabrication of DSRDM

### 2.3.1 Cutting, Rolling and machining process.

Three DSRDM sleeves were fabricated using AISI 316l plates. High-precision cutting, machining, rolling drilling, welding etc methods were used to maintain perpendicularity, straightness, parallelism and minimize heat-affected zones.

**Top Flange:** Top Flange of OD 437 mm, ID 290 mm was cut from 40 mm thick plate by using CNC abrasive water jet (Non thermal) cutting process to retain dimensional accuracy with machining allowances and eliminate the HAZ. Further machining operation were performed to achieve the required dimensional accuracy and tolerances.

A pitch circle diameter (PCD) of 407mm was marked, and 12 equi-spaced M12 tapped holes (18mm deep) were machined. In addition, 12 equi-spaced counter bored holes were prepared, each consisting of a 19mm diameter × 1mm deep counter bore transitioning to a 14mm diameter × 16mm deep bore at the opposite end. All drilling, tapping, and counter-boring operations were carried out on a vertical milling machine (VMC) using dedicated tapping and counter-boring canned cycle.

**Top Piece:** Top piece (OD 290mm, Length 2058mm) consisting of two parts, cylindrical shell of 290mm outer diameter was rolled from 5mm thick plate and long seam welded. 80mm thick, plate used to machine flange for connecting top piece and middle piece.

Flange of OD 290mm, ID 253mm was cut from 80mm thick plate by using CNC abrasive water jet cutting process to retain dimensional accuracy with machining allowances and eliminate the HAZ. Further machining operation were performed to achieve the required dimensional accuracy and tolerances. 12 nos. of Ø8H7 equi-spaced holes were match drilled at a to connect top and middle piece.

**Middle Piece:** The middle section is fabricated from a pipe that includes an initial uniform segment (OD 273 mm, ID 253 mm), a tapered transition zone, and a final reduced-diameter segment (OD 219 mm, ID 205 mm). The total length of the section is 2227 mm. After cutting the required portion from the parent pipe, both ends were accurately machined and subsequently match-drilled along with the top and bottom pieces to allow insertion of cylindrical pins.

The cutting operation was performed using a portable pipe-cutting and beveling machine (Figure 1), ensuring dimensional accuracy and uniformity in accordance with the specified requirements..



**Figure 1: Cutting & edge beveling**

**Bottom Piece** The bottom piece consists of three parts: a section machined from an 80 mm thick plate to achieve OD 219mm and ID 205mm, a second section machined from a 40 mm thick plate with OD 161mm and ID 147mm; and a 5mm thick plate formed into a conical shell through tapered turning.

**Cylindrical Pin:** Two types of cylindrical pins were machined from a 40mm thick plate, comprising 12 pieces each with Ø8 p6 × 6.5mm depth and Ø8 p6 × 18mm depth. Each pin was provided with an M3 × 4mm tapped hole at the centre to facilitate handling. All pins were chamfered 0.5×45° at the edges to ensure proper interference fit with the top–middle and middle–bottom pieces. After insertion, the pins were seal-welded in position to avoid crevices.

### 2.3.2 Beveling and Chamfering Process

To achieve proper fit-up and to reduce potential welding distortion, chamfering and edge conditioning were performed on all mating components. The cut ends of each sleeve segment were prepared with bevels to facilitate full penetration welds using butt joints. Chamfering and edge preparation were performed on mating components to ensure proper fit-up and minimize distortion during welding. All the sharp corners were smoothly blended, and the edges were rounded to a maximum radius of 0.3 mm.

The Top Piece was chamfered 1mm × 45° at both ends to facilitate alignment and to ensure a smooth, guided butt-weld joint—one end joining to the top flange and the other end to the flange–middle piece interface. The Middle piece was likewise chamfered 1mm × 45° at both ends to support proper alignment and guided butt-welding with the top piece and flange at the upper end and with the bottom piece at the lower end.

The Bottom piece, a Conical tapered component produced by taper turning on a lathe, was chamfered 1 mm × 45° at one end to enable accurate alignment and guided butt-welding with the middle piece.

All Cylindrical pins were chamfered 0.5mm × 45° at the edges to ensure proper interference fit with the Top–Middle and Middle–Bottom pieces. After insertion, the pins were seal-welded in position.



**Figure2: Flanges & conical shell**

### 2.3.3 Match Drilling:

The top piece, middle piece, and bottom piece were placed on rollers, and their cylindricity ovality, and straightness were checked using a dial gauge to ensure proper alignment. After achieving the required accuracy, the components were tack-welded in position. The assembly was then taken to the radial drilling machine, where match drilling of Ø8 H7, 24 numbers of holes was performed to maintain precise alignment across all pieces. After drilling, chamfering of 0.5mm × 45° was carried out on all drilled holes to remove sharp edges and achieve a clean finish. These holes were made to facilitate the insertion of cylindrical pins to avoid the welding distortion.



**Figure.3:Match drilled**



**Figure 4: Insertion of Pins**

### 2.3.4 Welding Process-DSRDM:

#### 2.3.4.1 Key Challenges:

To achieve the flatness 0.1mm, straightness of 0.5mm per 1000mm and perpendicularity of 1.0.the individual sleeve sections shall be joined using guided butt-joint welding to ensure precise axial alignment, structural integrity, and compliance with straightness tolerances while minimizing thermal distortion. Key challenges during welding include maintaining alignment of long cylindrical sections, controlling heat input to avoid ovality or bowing, and ensuring uniform penetration around the circumference. Proper fixturing, optimized welding parameters, and continuous dimensional monitoring are essential to achieve a distortion-free assembly.

#### 2.3.4.2 Welding Procedure Specifications (WPS):

The fabrication and modification of DSRDM sleeves involved multiple precision welding operations, primarily using the Gas Tungsten Arc Welding (GTAW) process. Welding was performed in 1G position with qualified welders, and Welding Procedure Specifications (WPS) [2] and Procedure Qualification Records (PQR) [3] were developed and approved per nuclear fabrication standards .

- AWS ER 16-8-2 diameter 1.2 mm filler wire in coil form was used for automated gas tungsten arc welding process.
- AWS ER 16-8-2 diameter 1.6 mm and diameter 2.0 mm filler wires in rod form were used for root and capping passes respectively during manual gas tungsten arc welding process.

#### 2.3.4.3 Typical weld parameters used for procedure qualification test coupons[1]

Pass	Root	Subsequence
Process	GTAW	GTAW
Position	1 G	1 G
Current (A)	80	120
Arc Voltage (V)	10	12
Filler wire dia.	Ø1.6	Ø2.0
Welding speed(mm/min)	75	90
Heat input (J / mm)	640	960

**Table 3**

Root Pass Weld	
Process	GTAW
Shielding gas	Argon (99.995%)
Back Purgig	Argon (99.995%)
Electrode	2% Thoriated diameter 2.4 mm (EWTh)
Polarity	Straight (DCEN)
Filler diameter(mm)	1.6
Filler material	AWS, SFA 5.9, ER16-8-2,

**Table 4**

Subsequent Pass Weld	
Process	GTAW
Shielding gas	Argon (99.995%)
Back Purging	Argon (99.995%)
Electrode	2% Thoriated diameter 2.4 mm (EWTh)
Polarity	Straight (DCEN)
Filler diameter(mm)	2.0
Filler material	AWS, SFA 5.9, ER16-8-2,
Inter pass Temperature.	< 120 °C
Gas flow rate (Shielding)	14 lpm
Gas flow rate (Purging)	10 lpm

➤ Table 5

➤ **2% Thoriated Tungsten (EWTh-2) : Advantages**

- **Easy Arc Starting & Stable Arc:** High electron emission ensures smooth and reliable ignition.
- **Higher Current Capacity:** Runs cooler; ideal for SS, CS, and nickel alloy welding.
- **Longer Electrode Life:** Reduced wear means less frequent grinding.
- **Best for DCEN Welding:** Offers deep penetration with a smooth, focused arc.
- **Maintains a Sharp Tip:** Ensures consistent, high-quality welds.

➤ **Use more than 2.4% Thoria in thoriated tungsten electrodes are Higher radioactivity risk (according to AWS/ISO)**

**2.3.4.4 Weld Fabrication of DSRDM Sections:**

The Top Flanges welded to the Top pieces using 5 mm Fillet weld performed by the TIG welding process to achieve a sound structural joint



**Figure 5: The Top Flanges welded to the Top pieces using 5 mm Fillet weld performed by the TIG.**

The Top piece and the Middle piece were joined using a guided butt TIG-welded, and at the interface where the top piece terminates, an additional fillet weld was applied to ensure proper reinforcement. To minimize thermal distortion during welding, the top

piece with flange and the middle piece were match-drilled, and cylindrical pins were inserted. A 1 mm TIG seal weld was then performed around the pins to lock the alignment. Subsequently, the middle piece was joined



**Figure 6: Guided Butt joint b/w Top & Middle Piece, 5mm Fillet weld b/w Top end & Middle Piece, 1mm seal weld around pins.**

Subsequently, the Middle piece was joined to the Bottom piece through a guided butt weld, and a fillet weld was deposited at the termination area to strengthen the joint. To further control weld distortion, the bottom piece was match-drilled with the flange, cylindrical pins were inserted, and a 1 mm seal TIG weld was applied.

Finally, the Bottom piece was fillet-welded to the Conical Shell to complete the assembly.

Seal Welds were applied on Ø8 Cylindrical Pins after insertion to prevent gas leakage. All Welding were performed in 1G position with qualified welders.



**Figure 7: Guided Butt joint b/w Middle end & Bottom Piece. 1mm seal weld around pins 5mm Fillet weld b/w Bottom end & Conical shell.**

**2.4 Inspection of DSRD Sleeve**

**2.4.1 Quality Assurance Plan**

Quality Assurance Plan (QAP) was prepared listing out various activities, sequencing of manufacturing, inspection stages, pickling-passivation and agencies responsible etc., It also listed the scope of activity for each agency for systematic follow up during all stages of manufacturing. Inspection of the vessels was carried out as per the QAP.

**2.4.2 Visual testing**

Visual and dimensional inspections execution of five weld joints per sleeve while ensuring that the overall

straightness was within 0.5 mm and perpendicularity within 1.0 mm across the full length. This demanded precise fixturing, alignment, and controlled welding procedures.

All individual parts, subassembly of parts, and also final assembly were subjected to 100% visual examination to check the soundness of the parts. The part shall be free from scratches, dents, tears or any other defects that are affecting the thickness of the parts in particular. The entire surface of formed parts shall be subjected to 100% visual examination to check the soundness of the parts. Thorough visual examination of all weld joints shall be carried out after each pass of weld. Improper surface finish, weld spatter, surface crack and surface porosity are not permitted

#### **2.4.3 Liquid penetrant examination:**

Liquid penetrant inspection was carried out as per ASTM E-165 & ASME B&PV code sec V Article-6. The acceptance criteria are as per ASME B&PV code Sec VIII Div-1. The edges of beveled plates were subjected to LPE before forming the shell. The entire surface of formed dished ends were also be subjected to LPE. Weld edge, root pass and final pass (including HAZ, minimum 1/2" on either side of the weld) of all weld joints were subjected to 100% Liquid Penetrant Testing (LPT) on root and final passes. Where ever 100 % radiography is not possible, LPE was carried out on each pass of weld joints [4].

#### **2.4.5.3 Radiography examination**

Radiographic Testing (RT) of all accessible butt joints. all butt weld joints (Total 26.06 meters length 2-2T RT quality) were subjected to 100% X-Ray radiography according to ASME B & PV code Sec V Article 2 & ASTM E-94. The acceptance criteria for radiography are as per ASME B&PV code Sec VIII Div-1. [6]

### **2.5 Geometrical feature measurements**

#### **2.5.1 Straightness & perpendicularity Measurement**

Firstly, string wire was tied tightly at the both end of lengthy test vessel. Now a transparent water tube was filled with water, ensuring no air bubbles in it. The water filled tube was used to check level of test vessel by adjusting roller support in which the entire large size test vessel was kept. The perpendicular of test vessel flange w.r.t shell was measured by using plumb bob and it was less than 1.5 mm.

#### **2.6 Pressure Hold Test:**

calibration of pressure gauges, piping with valves fittings, end connecting flanges with gaskets kept ready and 24 hours pressure hold test at 10mbar (g) conducted individually using nitrogen gas and observed no pressure drop.

### **3.0 Conclusion**

WPS, PQR & WOPQ were developed for welding of DSRDM Sleeve Assembly. The sleeve assembly is a slender in nature and made from austenitic stainless steel, weld distortion is inevitable due to its physical properties like poor thermal conductivity and high coefficient of thermal expansion. Sequence welding technique and use of welding fixture , assembly was successfully fabricated meeting all the manufacturing & NDT specification with an acceptable level of ASME section VIII Div-1 code. A close control of overall dimensions, distortion was achieved by proper adoption of joint design, joint preparation and welding technique.

### **4.0 Acknowledgement**

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