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**Y-12 DEVELOPMENT ORGANIZATION
TECHNICAL PROGRESS REPORT**

**Part 4 - Assembly Technology/Compatibility
and Surveillance (U)**

Compiled by
W. G. Northcutt, Jr.

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Prepared by the
Oak Ridge Y-12 Plant
P.O. Box 2009, Oak Ridge, Tennessee 37831-8169
managed by
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ASSEMBLY TECHNOLOGY/COMPATIBILITY AND SURVEILLANCE

CONDUIT FABRICATION—GEM MAGNET SUPERCONDUCTING SUPER COLLIDER

M. W. Doughty and J. C. Yearwood

Summary

The Super Collider is a high-energy scientific instrument composed of a 53-mile-long ring of proton accelerators designed to collide protons and evaluate the emanating particles. The Oak Ridge Y-12 Plant is under contract to perform work for the Superconducting Super Collider Laboratory (SSCL) and has been asked to develop manufacturing processes for components of the gammas, electrons, muons (GEM) detector.

Three welded subassemblies are involved in the fabrication of these conductors. The superconducting cable is enclosed in a stainless steel conduit, which is then enclosed in an aluminum sheath. The ends of the conductor are terminated with a connector assembly joined to the superconductor, the conduit, and the sheath.

Initially, the conduit weld was to be a single-pass, autogenous gas-tungsten arc weld. The authors made a great effort to get full penetration without root reinforcement on the inside of the tube. When the authors were unable to meet all of the weld requirements with an autogenous weld, they shifted development efforts to making the weld using an automatic gas-tungsten arc tube welding head with an integral wire feeder. Because reinforcement at the root continued to be a problem, the authors decided to make the weld in two passes. To achieve the desired weld reinforcement on the outside of the tube, the authors developed a welding procedure in which an autogenous pass is used to join the tube ends with the necessary minimum pushthrough on the inside of the tube and filler metal is supplied during the second pass. This two-pass weld required a weld joint with a flat butt for the root pass and a V-groove for the filler metal pass. A 272-ft conduit was made using this two-pass welding procedure for a test at the University of Wisconsin.

Introduction

The Super Collider is a high-energy scientific instrument composed of a 53-mile-long ring of proton accelerators designed to collide protons and evaluate the emanating particles. Two detectors in the magnet ring evaluate the collisions and the resulting particles. The Y-12 Plant is under contract to perform work for SSCL and has been asked to develop manufacturing processes for components of the GEM detector. This detector is composed of a large (63-ft-diam), electromagnetic coil wound with superconducting cable. Each of the superconductor assemblies used to wind the coil is $\sim 3/4$ of a mile long.

Three welded subassemblies are involved in the fabrication of these conductors. The superconducting cable is enclosed in a stainless steel conduit, which is then enclosed in an aluminum sheath. The ends of the conductor are terminated with a connector assembly joined to the superconductor, the conduit, and the sheath. Figure 1 shows the relationship of the conductor, the conduit, and the sheath.

The superconductor cable is made of niobium-titanium (Nb-Ti) filaments in a copper matrix. The 0.750-in.-diam cable is wrapped in a stainless steel foil sheeting for protection. As received, the stainless tubing has a nominal inside diameter of 1.125 in. and a nominal wall thickness of 0.120 in. Once the lengths of tubing have been joined to form the conduit, the cable is pulled through the conduit using a smaller steel cable and a winch. The conduit and

the conductor cable that is inside are drawn through a die to reduce the outside diameter to 1.027 in., leaving ~34% void within the conduit for the circulation of liquid helium for cooling.

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Fig. 1. Components of the conductor assembly.

Prior Work

This study is the first report of GEM weld-development work.

Presentation of Experimental Work

Single-Pass Procedure Development. The authors chose 3/4-in. schedule 40, type 304L stainless steel seamless pipe for the initial development work. Initially, the weld joint was a flat butt weld. The conduit was supplied in 20-ft lengths, which were to be joined using an automatic tube welder to perform an autogenous (without adding any additional filler metal) weld using the gas-tungsten arc welding (GTAW) process. After all of the lengths were joined, the superconductor could be pulled through. Once the cable was in place, the pipe would be drawn down to the final dimensions.

The only pipe available for the early development work was seamed pipe of poor dimensional quality. Using this pipe, the authors made welds with penetrations ranging from

50% to 100%. During this early phase of weld development, several areas of concern became apparent, including tube alignment, internal weld-bead protrusion, and external weld-bead depression.

Because the cable has to be pulled through the full length of the tubing (3/4 mile for the full-scale GEM coils), the inside surface must be free of restrictions and sharp edges. In the beginning, alignment of the tube ends was left to the integral clamps on the tube welding head. These clamps, however, were insufficient for aligning even short pieces of tubing. The problem of external alignment was compounded by the fact that the wall thickness, and therefore the position of the hole, varied throughout the length of the tube. A more reliable method of ensuring internal alignment was needed. An internal alignment tool was made, first of a fiber material and later of tool steel. The fiber tool could not withstand the heat from the welding process, and the steel tool was cumbersome to operate and prone to getting stuck inside the tube. Remember, the weld joint would always be at least 20 ft from an open end of the conduit. As part of the initial inspection process, the minimum and maximum wall thicknesses were recorded for each end of the lengths of tubing. Internal misalignment was reduced to an acceptable level by joining the thick-to-thick and the thin-to-thin areas of the tubes.

Structurally, having 100% weld penetration in the tube wall was desirable. However, weld protrusion had to be kept to an absolute minimum to avoid restricting the cable pulling. Early on, the authors considered several methods of reaming or grinding the inside surface of the weld. This approach was abandoned, however, because of the 20-ft distance from the weld area to the open end of the tube.

Initially, the weld was to be a single-pass autogenous weld. The authors made a great effort to get full penetration without root reinforcement on the inside of the tube. They adjusted all important welding parameters, including gas mixture. At one point, they added hydrogen to the shielding gas to increase penetration while keeping the weld as narrow as possible. The relationship of the sulphur content of the stainless steel to weld penetration also became an important factor.

Although making a single-pass autogenous weld meeting the requirements of full penetration without inside reinforcement was possible, the outside weld bead often had several thousandths of an inch underfill. This depression was unacceptable both structurally and for purposes of nondestructive evaluation. This problem of protrusions and depressions of the weld bead was aggravated by the fact that the tube had to remain stationary because of its ever-increasing length, and the weld head rotated around the tube. This fact meant that, for some of the weld, gravity was pulling the weld puddle toward the center of the tube while at other times gravity was pulling the puddle toward the outside. No set of parameters would give the same weld-bead characteristics for the entire weld. This problem, which was caused by gravity, was alleviated somewhat by the fact that the tube welder could be programmed with different parameters for different segments of the weld cycle. Figure 2 shows a metallographic cross section of the single-pass autogenous weld.

Two-Pass Procedure Development. When the authors were unable to meet all of the weld requirements with an autogenous weld, they shifted development efforts to making the weld using an automatic tube welding head with an integral wire feeder. In an autogenous weld, any weld reinforcement, whether inside or outside, must be made of material from the tube itself. The addition of filler wire allowed for more control of the size and shape of the outside weld reinforcement.

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Fig. 2. Single-pass autogenous weld at 7X.

The ends of the tube were beveled to provide a V-groove joint for the filler metal. Although the wire-fed weld provided excess weld metal to ensure that no depressions existed on the outside surface, the inside weld reinforcement was difficult to control.

At this point, the authors decided to make the weld in two passes. An autogenous pass would be used to join the tube ends with the necessary minimum pushthrough on the inside of the tube. Filler metal would be supplied during the second pass to achieve the desired weld reinforcement on the outside of the tube. With this approach, the difficult task of reaming or grinding the internal weld surface was eliminated. The excess material on the outside surface could be removed easily to the desired finish for nondestructive evaluation.

This two-pass weld required a weld joint with a V-groove for the filler metal and a flat butt for the root pass. The resulting thinner wall at the root made any variation in the overall wall thickness much more critical. To eliminate these variations, the authors cut the bevel in the end of the tube with reference to the inside surface, thus giving the land, or flat part of the joint, a constant thickness, and any variation in the tube wall was absorbed in the beveled section.

Finalized Welding Procedure. The final weld-joint design consists of a 42.5° bevel angle with a 1/16-in. land (Fig. 3). This joint is applied to the tube ends with a portable cutting tool clamped to the inside of the tube by an expanding mandrel. The rotating head has two cutters, one for the land and one for the bevel. These cutters are positioned so that no matter how much material is removed from the tube end, the weld joint dimensions remain the same.

Welding parameters developed for conduit fabrication are detailed in Table 1. The root pass is made using an automatic tube welder without the addition of filler metal. The cover pass is applied using an automatic tube welder with a wire feed unit. The tube ends

are aligned with reference to the outside surface in a trough-shaped fixture. Preference is given to wall thickness variations discovered during dimensional inspection of the tubing. A bore scope is used to inspect for weld penetration and weld protrusion on the inside of the tube. The outside weld reinforcement is removed with a belt sander. Figure 4 shows the final weld after the wire-fed second pass.

Fig. 3. Final conduit weld joint design.

Table 1. Conduit welding parameters

Root pass		
Machine	Arc machine	Model 9-15
Current	90/40 A	
Pulsed	1.0/0.4 s	
Speed	0.7 rpm	
Cover pass		
Machine	Arc machine	Model 81
Current	65 A	
Speed	5.0 rpm	
Wire feed	15 ipm	
Welding gas		
Shield	Argon	17 cfh
Purge	Argon	10 cfh
Filler wire		
Material	308/308L stainless steel	
Size	0.035 in.	
Electrode		
Type	Tungsten-1.5% lanthanum	
Diameter	3/32 in.	
Grind	18° angle/0.030-in. flat tip	
Gap	0.030 in.	

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Fig. 4. Conduit weld after a wire-fed pass at 7X.

Conclusion

Based on experimentation and discussions with welding vendors, the 0.120-in. wall thickness was near the limit for a single-pass autogenous weld. Even slight variations in wall thickness or roundness caused unacceptable variations in penetration and reinforcement. If this tubing was being made to carry liquids or gases, there would have been no need to develop this weld. This type of tubing is routinely joined using GTAW with a single autogenous pass. Although a number of machines, procedures, and specifications for automatic tube welding are now being used, the physical restraints placed on the SSC conduit separated this weld from the routine.

The Y-12 Plant has played a critical role in producing some, if not all, of the first hardware components for the GEM detector. The customer is extremely pleased with our progress and is already using our products to sell this project.

Future Work

At this point, only the fabrication techniques for the conduit have been developed. A 272-ft conduit has been made for a test at the University of Wisconsin. Although the sulfur content of the early development tubing was fairly high, the sulphur content of the tubing obtained later for the University of Wisconsin tests was much lower; therefore, the authors were unable to duplicate the weld that they had developed. More of the original tubing had to be obtained for fabrication of the 272-ft conduit, which, with the superconducting cable inside, will be combined with the aluminum sheath and end connectors to make a subscale coil for evaluation. This work will be reported in detail later.

The fabrication of the aluminum sheath is now being addressed. In addition to welding two aluminum halves around the conduit, a coextrusion process that will overlay a 2-in. by 3-in. aluminum sheath around the conduit is also being considered.

References

None.

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