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SLEEVE EXPANSION OF BOLT HOLES IN RAILROAD RAIL

Volume II - Process Parameters and Procedures

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16. Abstract

The bolt-hole cold-expansion process has been applied to railroad rail in laboratory tests and has demonstrated a potential for the reduction of rail-bolt-hole-failure incidence. Limited field tests also have been conducted and are currently under long-term evaluation. Because the process is not common to the rail industry, this procedures manual has been prepared to assist in process implementation.

The procedures manual describes the process, and provides instruction and recommendations for field application, and establishes the requirements for bolt-hole and tool-size relationships.

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PREFACE

This document is Volume II of a three-volume series. Volume I reports the results of a investigation of several processes that introduce compressive residual stresses into the rail joint to improve fatigue resistance and describes the planning and implementation of a field experiment to verify the fatigue improvement anticipated for the sleeve-expansion process. Volume II defines process parameters and outlines procedures for process control of the sleeve-expansion process. Volume III reports the results of a field experiment to evaluate the sleeve-expansion process and the results of three associated experiments:

- Studies on the effect of negative fatigue ratio (reverse bending) on rail sections with cold-expanded (sleeve-expanded) bolt holes

- Investigation of flaw growth in vacuum

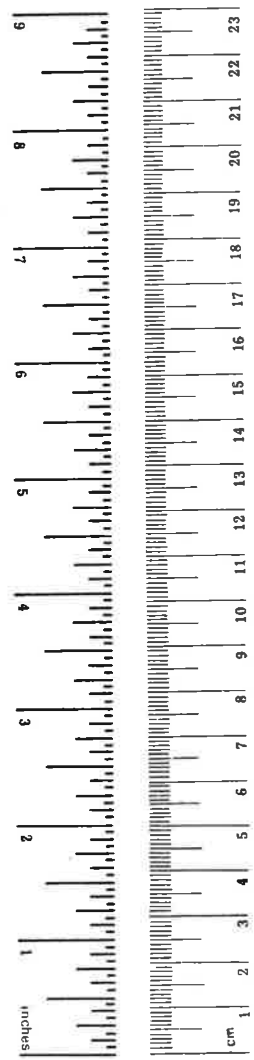
- Life of flash-weld rail joints fabricated from uncropped rails with cold-expanded and non-cold-expanded holes.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

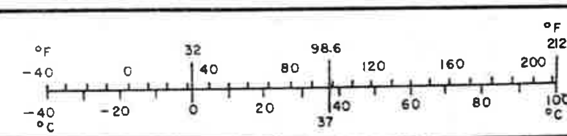
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ABBREVIATIONS AND SYMBOLS

ksi	pounds per square inch in thousands
lb/yd	pounds per yard
psi	pounds per square inch
R_C60	hardness - Rockwell C scale
RHR	roughness height standard for metal surface finish

1. INTRODUCTION

A high percentage of railroad rail that must be replaced is attributable to rail-web fatigue cracks initiating at rail-joint bolt holes. It has been demonstrated (ref 1) that introduction of large compressive stresses in metal surrounding a bolt hole will prolong hole-initiated fatigue failure by an order of magnitude. The required compressive stress is achieved by cold expanding the bolt hole 0.05 to 0.08 inch (ref 2).

Various methods have been attempted to achieve the desired cold expansion. Two unsuccessful methods used on rail are:

1. British rail–driving or pressing a bulb-headed or stepped bar through the bolt hole (fig. 1)

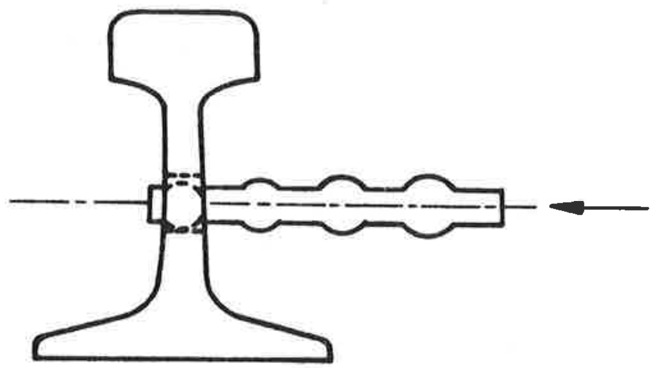

Figure 1. – Stepped Bar Expansion

2. Some U.S. railroads–edge coining of the holes (fig. 2)

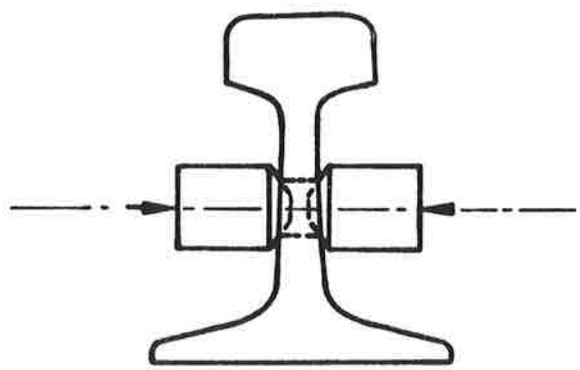

Figure 2. – Edge Coining

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[1]Phillips, J. L., *Fatigue Improvement of Sleeve Cold Working,* SAE 730905, October 1973.

[2]Lindh, D. V., et al., *Sleeve Expansion of Bolt Holes in Railroad Rail,* D6-44287, December 1977.

In the first case, reasonable tool life could not be expected if sufficient hole expansion is achieved, given the field problems of grit-free wet lubrication, hole smoothness, tool metal pickup, etc. In the second case, little or no compressive stress is achieved at the center of the web. With this condition, very little fatigue improvement could be anticipated.

The application of the sleeve cold-expansion process to the bolt hole resolves these problems. The process will provide (1) the desired compressive stress surrounding the bolt hole, (2) very long mandrel life, and (3) a cycle time per hole of 20 seconds, and will permit the use of readily portable equipment.

The basic reason for the success of the sleeve-cold-expansion process lies in the sleeve. The split, dry-film-lubricated sleeve, placed on the undersize portion of the tapered mandrel, is drawn into the hole and stopped by either a flare on the sleeve or pullgun nosepiece impingement. Thus, the sleeve locks in the hole, providing a smooth, properly lubricated bore through which the mandrel can be drawn with comparative ease. This approach permits relatively low pull forces and long mandrel life.

The sleeve dry-film lubricant is the item most critical to the process and is the item that makes the process work. The dry-film lubricant is bonded to the sleeve under closely controlled conditions, with an accuracy that would be impossible to obtain with wet lubricants, especially wet lubricants applied under field conditions of varying temperature, humidity, and cleanliness.

The sleeve proper is fabricated from full hard, 300-series stainless-steel strip; the flat rolled strip providing the desired hardness, thickness, and surface finish. The use of stainless steel also provides sufficient corrosion resistance to permit long-term storage without damage to the dry-film lubricant.

The only drawback to this process is that the sleeves may be used only once. However, if the cost of sleeves is compared to the cost of other approaches and the limited effectiveness obtained with other methods, the economics strongly favor the sleeve approach.

An extensive laboratory test has been conducted (ref 2), wherein approximately 72 2-foot-long sections of 112-lb/yd rail were prepared as specimens of two-bolt-hole and four-bolt-hole configuration. All holes were bored with spade-type drills commonly used on track. One-half of the specimens then were cold expanded 0.055 inch with the sleeve process. No additional hole treatment (such as deburring) was accomplished prior to fatigue testing.

The fatigue test results indicate that 10 times the life expectancy can be anticipated from the cold-expanded specimens before hole-initiated failure occurs. This same superiority holds true for conditions where the hole has been elongated after cold expansion (by the bolt) and where fretting of the bolt-hole bore has occurred. In the case of rail specimens where a 0.125-inch-long crack at the hole was introduced prior to testing, the normally drilled rail lasted a limited number of fatigue cycles. The cold-expanded specimen with an equivalent crack lasted 300 times longer. Forty-five percent of the cold-expanded specimens tested to failure did not fail in the hole; web failures were common; and one specimen failed in the rail head.

Specimens with web-initiating failures produced six to ten times the life expectancy of the non-cold-expanded specimens, all of which failed in the hole.

It appears likely that sleeve-cold-expanded bolt-hole treatment, properly applied, could prolong track inspection and maintenance cycles to at least five times that required for nontreated bolt holes.

2. FIELD PROCEDURE

The following procedure is directed to field application on laid track. Rework of rail, frogs, or switches accomplished in a factory or shop environment may require equipment adaptation to obtain maximum efficiency.

2.1 HOLE SIZE SELECTION

To achieve effective cold expansion, the hole must be expanded to produce 3.5 to 5% strain. The starting hole sizes listed in section 4.3, (table 1), must be selected and coordinated with the proper mandrel size (sec. 4.5, table 3). The mandrel size and sleeve thickness (0.012 inch), in conjunction with the starting hole size, produces the required strain.

In practice, rail that has been in service for an extended period is not likely to contain bolt holes that are round and of a specific diameter; considerable ovality will probably be encountered. To overcome this problem, the maximum anticipated hole ovality in a track system planned for rework must be established. This figure will then establish the starting hole size. For example:

- Original bolt hole diameter = 1.00 inch
- Maximum ovality, major diameter = 1.30 inches
- Starting hole size = 1.313 inches
- Starting hole tolerance (sec. 4.3, table 1) = 1.313 to 1.323 inches.

Note: If the starting-hole size does not meet the specified tolerance, cold-expansion effectiveness is seriously degraded.

2.2 HOLE PREPARATION

Assuming that the starting-hole size required has been selected (sec. 2.1), the method for achieving the size must be selected. If, for example, a track system originally bored for 1.25-inch-diameter holes shows no ovality exceeding 1.3125 inches, then the maximum bore diametrical increase is 1/16 inch. This amount of bore increase can be accomplished with broaching. For bore increases exceeding 1/16 inch, multiple-step broaching, drilling, or some form of punching would be required. The surface roughness of the prepared hole should be 500 RHR or better. Taper of the prepared hole should be included within the total hole tolerance shown in section 4.3, (table 1) .

2.3 EQUIPMENT SELECTION

Equipment is currently available to accomplish rail broaching operations. Standard rail-track drill equipment must be modified to provide rapid alignment and piloting, if this method is to be used efficiently. Of the two methods, broaching is more rapid, given optimum conditions. In cold weather, the oil used to lubricate the broach thickens and draws metal chips into the broach-puller chuck, necessitating frequent chuck cleaning and slowing the operation. This condition, plus the rapid broach wear (approximately 400 holes per sharpening) encountered with grit-impregnated grease residual to field bolt-hole conditions reduces rapidity of broaching relative to drilling. In either case, the method selected must be considered in light of the total rail crew and the pace maintained by the joint breakdown and cleanup crews (ref sec. 3.0).

The use of punch-type equipment, possibly explosive driven, should certainly be explored.

2.4 COLD-EXPANSION PROCEDURE

Hole cold-expansion equipment consists of:

- Sleeves, figure 3 (sec. 4.4 and table 2)
- Mandrel, figure 3 (selected to hole size per table 3)
- Pull gun, figure 4
- Power supply, figure 5.

Note: The power supply illustrated requires a water-filtered compressed air supply. Engine-driven units are available, if such units would prove more practical. Information pertaining to sleeve, pull-gun, and power-supply acquisition is presented in the Appendix.

The normal sequence for cold expansion procedure is:

1. Install sleeve on reduced diameter portion of mandrel (near the chuck-grip end of the mandrel, fig. 3).
2. Insert mandrel in bore of bolt hole, grip end first (fig. 6).
3. Seat mandrel with stroke from plastic hammer. At this point, the mandrel should be fixed in the bolt-hole bore, with the sleeve nested in the bolt-hole bore, protruding on each side of the web (fig. 7).
4. Slip pull-gun nose over mandrel chuck end (fig. 8) and trigger pull gun. The mandrel should pull through the sleeve with no hesitation.
5. As the mandrel is pulled clear of the rail web, the pull gun trigger is released and the mandrel will be returned to the load position in approximately 5 to 8 seconds. The mandrel loader removes the mandrel from the gun, places a sleeve on the mandrel, and places the sleeve/mandrel assembly in the next hole.

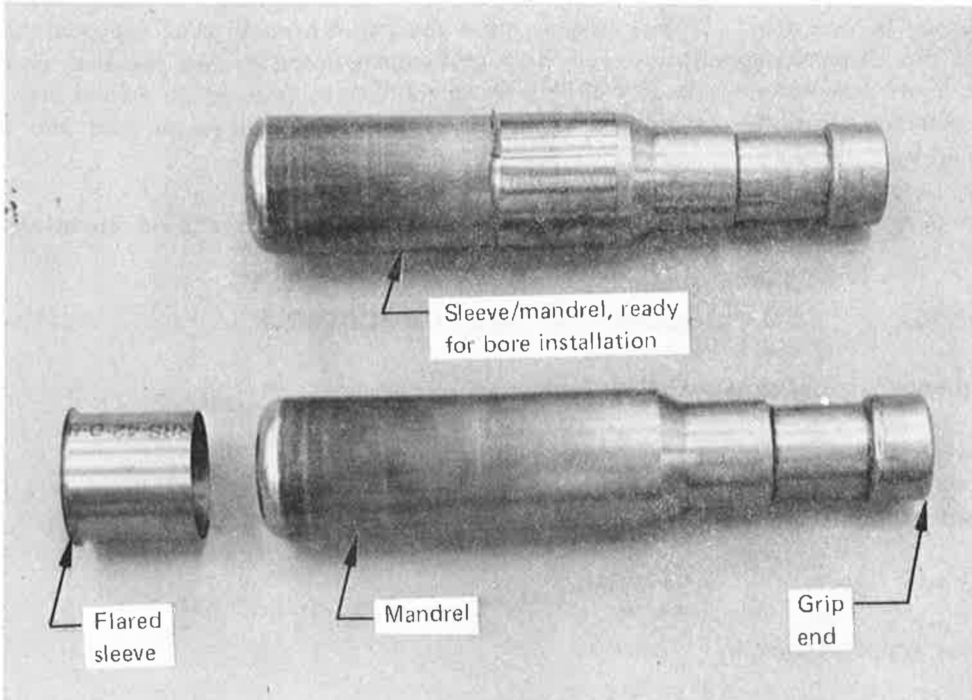


Figure 3. – Cold-Expansion Mandrel and Sleeve

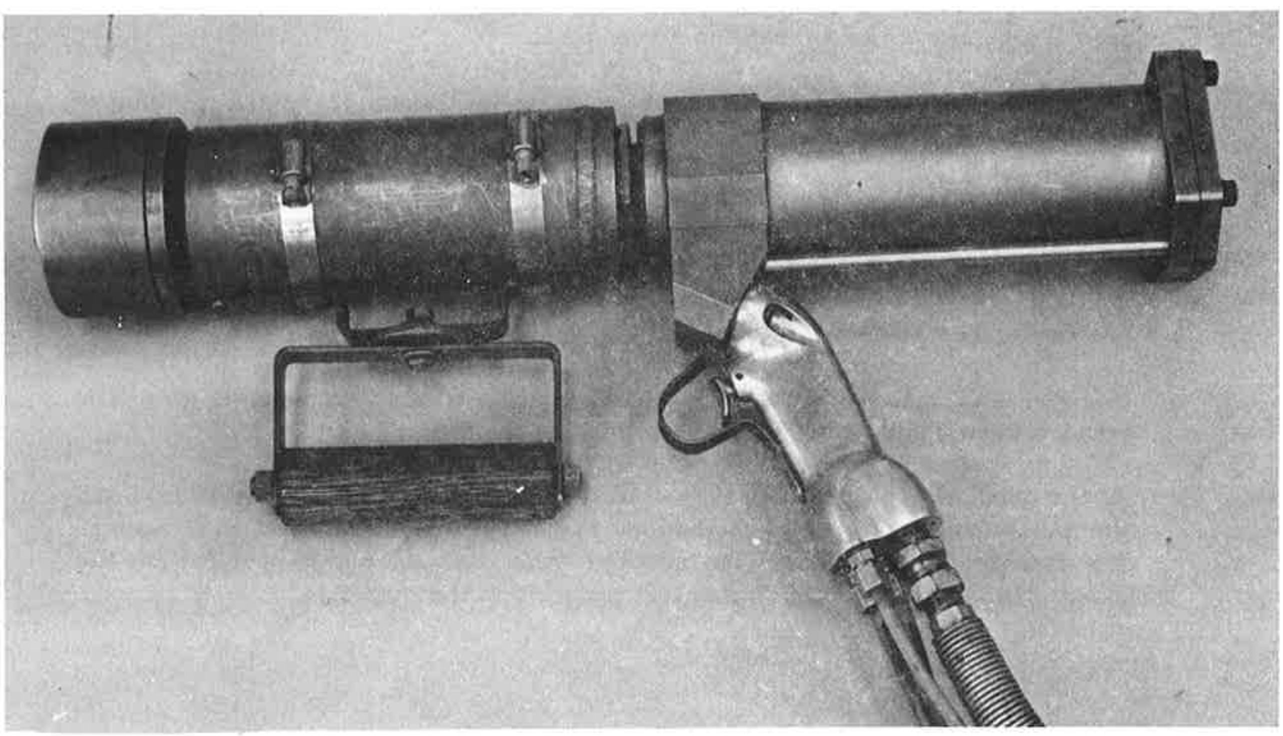


Figure 4. – Mandrel Pull Gun

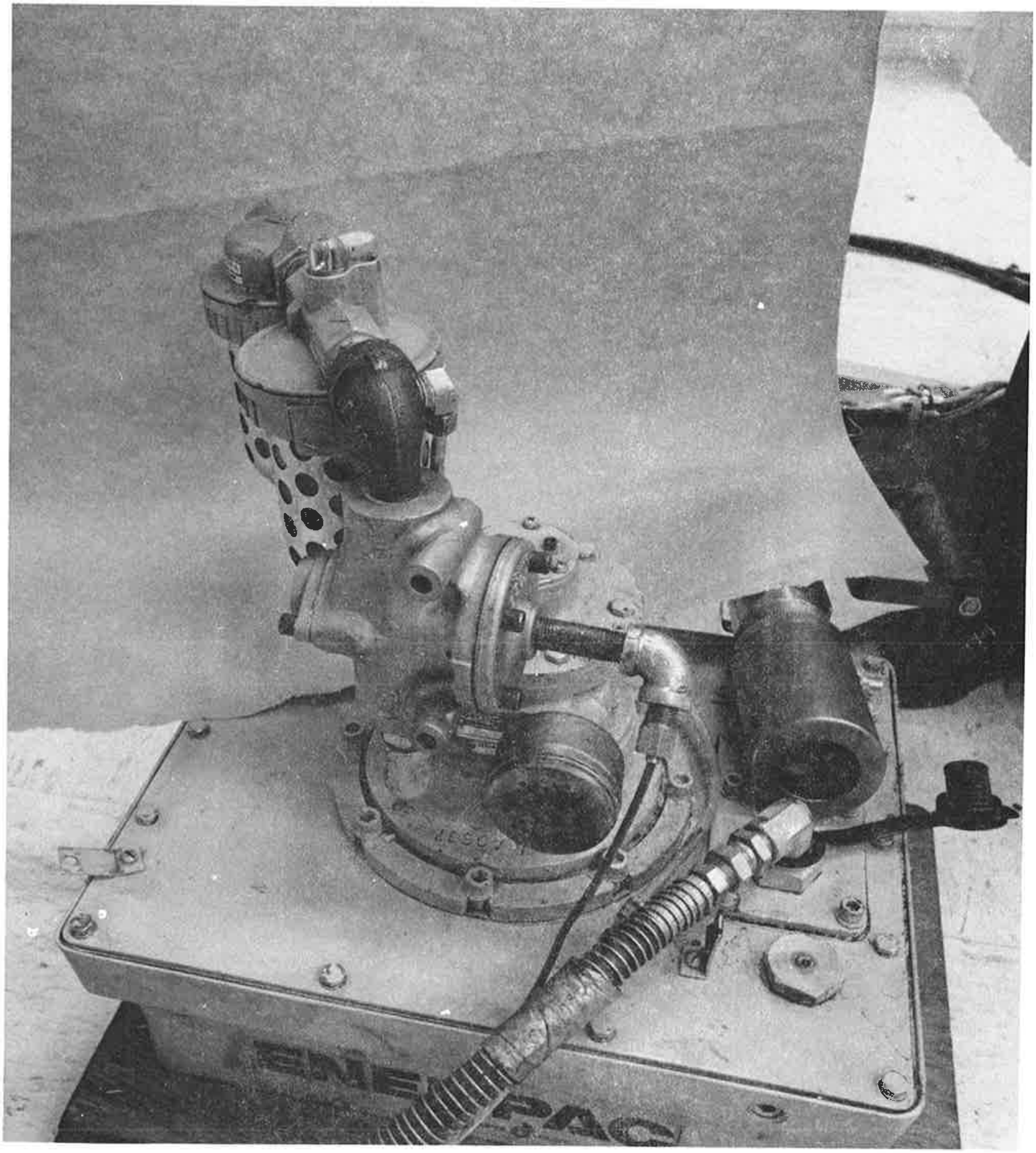


Figure 5. — Air-Actuated Hydraulic Power Supply

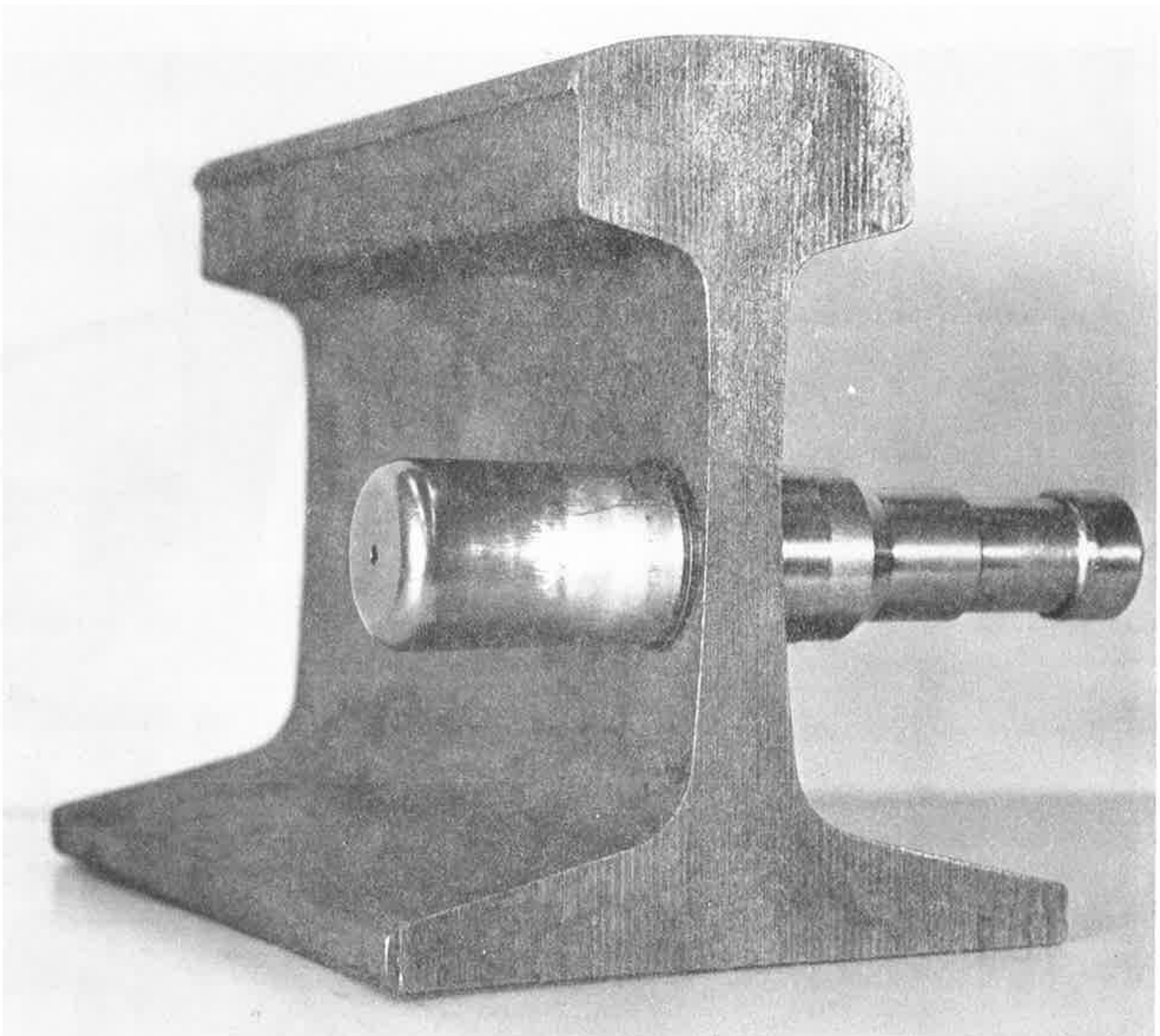


Figure 6. — Mandrel Inserted in Bolt-Hole Bore

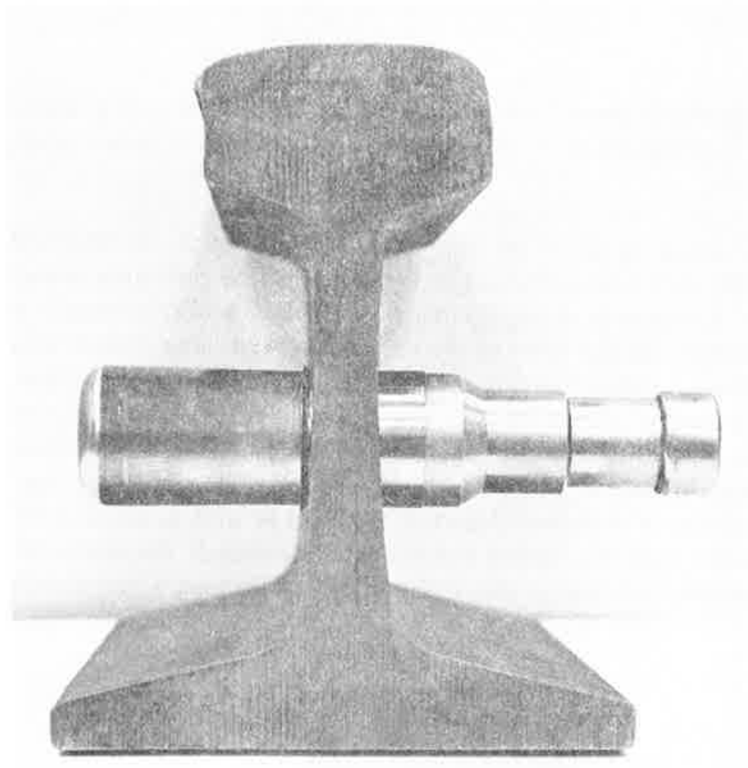


Figure 7. – Mandrel and Sleeve Properly Seated in Bolt-Hole Bore

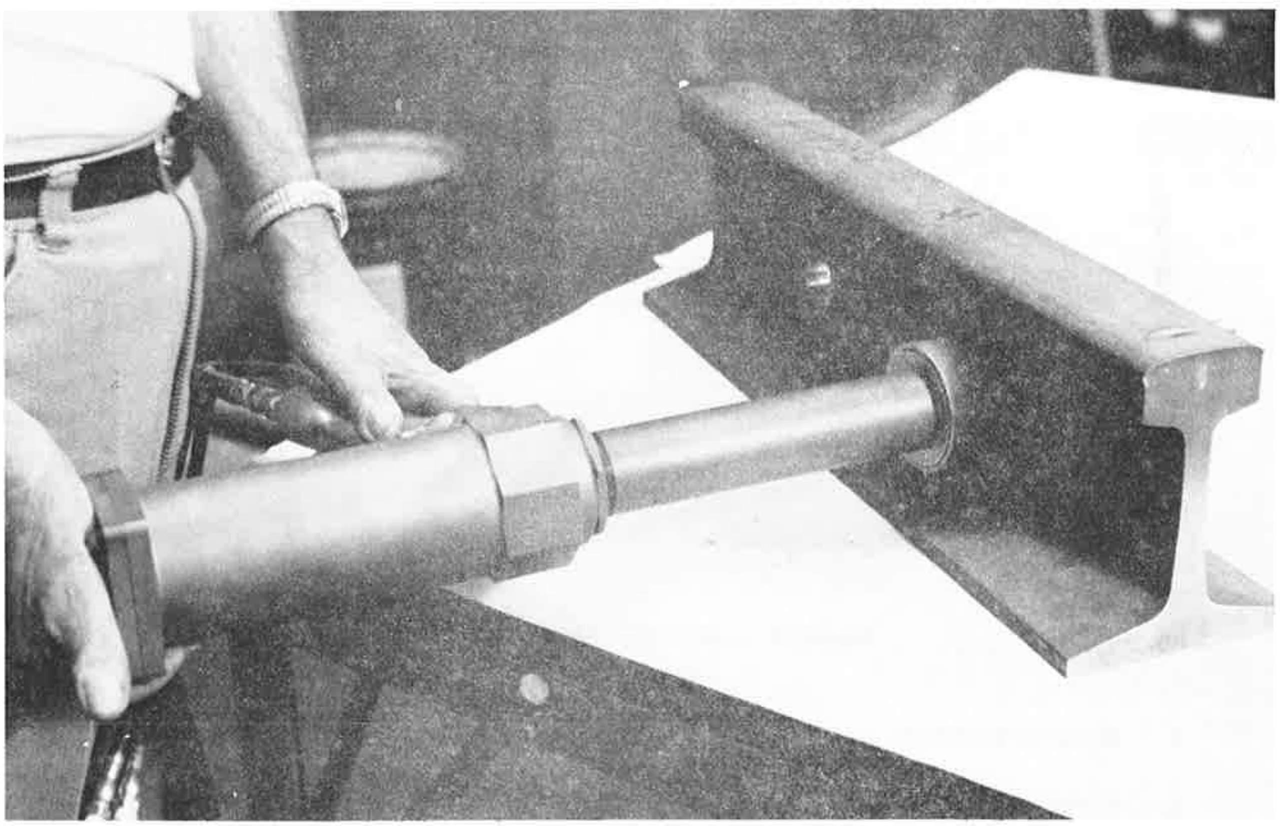


Figure 8. – Pull Gun Positioned to Cold-Expanded 131-lb Rail

The use of two mandrels permits one mandrel to be loaded and placed in the bolt hole while the second is occupied with the pull-gun retract and return cycles, reducing cycle time per hole.

For railroad rail work, a flare on the split sleeve (fig. 3) is desirable. The tapered configuration of the rail web reduces the accuracy of the pull-gun-nosepiece seat to rail web distance, the dimension normally used to predict a sleeve length that will ensure no contact of mandrel on the bore to be cold expanded. The flared sleeve locks in the bore due to the flare, rather than depending on the pull-gun-nosepiece seat, providing greater reliability for the sleeve lock. If the sleeve is allowed to slip, contact of mandrel to bore will occur, freezing the mandrel in the bore. Also, if the sleeve is allowed to spiral on the mandrel and is placed in the bore in this condition (fig. 9), contact will occur. A third problem is mandrel cleanliness. If oil or grit is allowed to build up on the mandrel to the point that the sleeve lubricant is damaged, the mandrel also will freeze in the bore. If a mandrel freeze is encountered, the following steps should be taken:

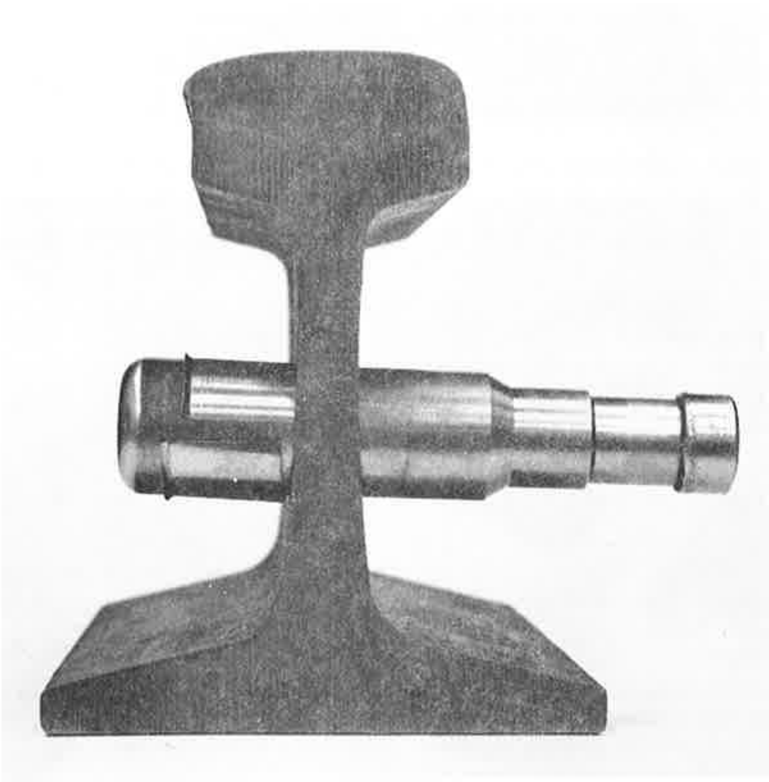


Figure 9. — Improper Sleeve Application

1. Remove pull gun.

2. Clear track crew away from the area from which the mandrel was inserted.

3. Using a spike maul, strike the mandrel on the grip end and drive it in the direction from which it was inserted.

CAUTION: The mandrel is very hard (R_C60) and a direct, square blow is required to avoid chipping the grip area. When the mandrel comes free it will travel 30 to 40 feet at high velocity. **KEEP TRACK CREWS CLEAR.**

2.5 GENERAL NOTES

To relieve the incidence of mandrels freezing in bolt-hole bores and equipment maintenance problems, the following precautionary items should be observed:

1. The split sleeves should be protected until actual use to ensure no damage to the dry-film lubricant.

2. The mandrel should be wiped frequently to remove grit and oil. The crewman installing the sleeves should wear absorbent material gloves (cotton, etc.) and should not touch oily or grease-covered tools (joint-bar repack and rebolt equipment); such oil or grease damages the sleeve lubricant.

3. The operator placing the sleeve mandrel in the hole bore must be trained to ensure that the sleeve is aligned and the mandrel seated. If pull-gun pressure is applied before the sleeve is seated, a twisted sleeve may result, causing the mandrel to freeze in the bore.

4. The area of rail web surrounding the bolt hole on the pull-gun side should be relatively free of oil or grease remaining from drilling or broaching operations. This residual oil, usually containing metal chips, should be removed from the rail-web contact area of the pull-gun nosepiece. The pull-gun nosepiece presses on the rail web with 6,000 to 8,000 pounds force. Residual oil under this pressure is extruded into the pull-gun chuck area. Metal chips and grit thus presented to the pull-gun chuck will, after a time, cause the chuck to jam, especially in weather of 45° F or colder.

5. The hydraulic power supply now available for the pull gun is generally trouble-free, with the exception of compressed-air-powered units. When used in cold weather (below 50° F), water in compressed air, in spite of water filters, tends to freeze up the air control system and the exhaust system of the air-powered units. Gasoline-engine-powered units with mechanical or electric trigger control to the pull gun are less susceptible to these problems.

3. PROCESS LABOR REQUIREMENTS

Actual cold-expansion-process application to field track rebuild and maintenance must be sequenced to track-joint breakdown pace if costs are to be kept within reason.

Assuming a breakdown crew using left- and right-hand bolt machines (two total) and left- and right-hand joint cleanup brush crews (two total), and one broach crew using one broach puller and two broaches, the broach operation will be the pacing item. The use of two broach pullers and four broaches will force the pace on the cleanup crews. A single cold-expansion pull gun used with two mandrels can maintain or exceed the pace of the two cleanup crews.

If rail drilling equipment is used, mounted in a fashion similar to rail-bolt machines and provided with rapid indexing and pilot-drill devices, left- and right-hand units could probably pace close to the rate of joint cleanup crews. A typical crew would then be:

1.	Debolt and bar removal	
	Left	2 men
	Right	2 men
2.	Joint cleanup	
	Left	2 men
	Right	2 men
3.	Drilling	
	Left	2 men
	Right	2 men
4.	Cold expansion	3 men
	(one gun operator)	
	(one mandrel inserter)	
	(one sleeve removal and support)	
	Total	15 men

5. Packing and bar replacement–as required.

If a single broach setup is used, three men are required on the crew:

1. **Broach puller operator**

2. **Broach placement man**

3. **Broach lubricator**

The use of the normal, manually moved and aligned single-track drill, considering the long setup time of this unit, would cause a very slow drill rate.

4. PROCESS CONTROL REQUIREMENTS

4.1 REQUIREMENTS

1. These special instructions establish the requirements for sleeve cold expansion of railroad rail-joint bolt holes.

2. The requirements are applicable to all rail configurations using 1.00-through 1.50-inch-diameter bolt holes.

3. Contractors or operators processing rail bolt holes should follow the procedures outlined in section 2.0.

4.2 PROCESS

The sequence described below must be followed to achieve the correct cold expansion:

1. Select the starting hole size (sec. 4.3).

2. Produce this hole size in the rail within the specified tolerance of section 4.3.

3. Select the corresponding sleeve size (sec. 4.4).
   Note: Purchase sleeves to the requirements of section 4.6.

4. Select the corresponding mandrel size.

The coordination of starting-hole size, sleeve size, and mandrel size will provide the correct interference between mandrel/sleeve and hole, which varies from 0.050 inch on 1.00-inch holes to 0.070 inch on 1.5-inch holes.

4.3 STARTING HOLES

The rail holes to be cold expanded shall be drilled, reamed, broached, or punched to meet the minimum/maximum diameters specified in table 1.

4.4 COLD-EXPANSION SLEEVE

The cold-expansion sleeve shall be made from full-hard 301 stainless steel 0.012 inch in thickness. The inside of each sleeve shall be coated with a qualified thickness (ref sec. 4.6) of FEL PRO C300 lubricant. The sleeve dimensions and inspection tool dimensions are presented in figure 10 and table 2.

Table 1. — Starting-Hole Dimensions

Minimum diameter (in.)	Maximum diameter (in.)
1.000	1.010
1.062	1.072
1.125	1.135
1.188	1.198
1.250	1.260
1.313	1.323
1.375	1.385
1.438	1.448
1.500	1.510

Note: The major and minor axes of an oval hole shall not exceed the minimum and maximum diameters shown in table 1.

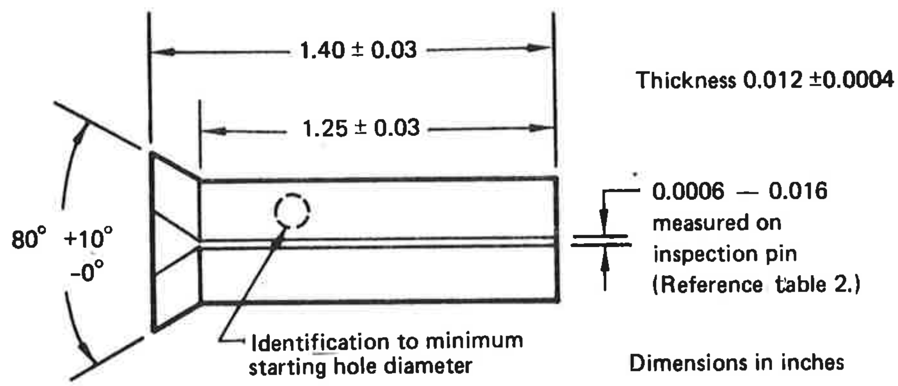


Figure 10. — Flared Sleeve

Table 2. — Sleeve Size

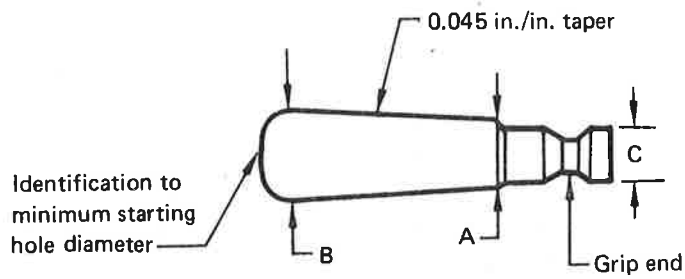
Minimum starting hole diameter (in.)	Inspection pin diameter (in.)
1.000	0.966
1.062	1.028
1.125	1.091
1.188	1.154
1.250	1.216
1.313	1.279
1.375	1.341
1.438	1.404
1.500	1.466

4.5 COLD-EXPANSION MANDREL

The cold-expansion mandrel shall be made from steel heat trated to 300 ksi (R_C57 to 61). Mandrel sizes are listed in table 3.

Table 3. — Mandrel Size

Starting hole minimum diameter (in.)	A (in. ±0.0002)	B (in. ±0.0002)	C (in. ±0.010)
1.000	0.966	1.026	0.990
1.062	1.028	1.090	1.000
1.125	1.091	1.156	1.000
1.188	1.154	1.221	1.000
1.250	1.216	1.286	1.000
1.313	1.279	1.351	1.000
1.375	1.341	1.416	1.000
1.438	1.404	1.481	1.000
1.500	1.466	1.546	1.000



Note: Vascojet MA steel is recommended.

4.6 QUALIFICATION OF LUBRICANT-COATING THICKNESS

The lubricant coating on each batch of sleeves shall be verified by cold working 1.250-inch maximum diameter starting holes with an edge margin of 2.0 inches in a piece of mild steel plate, 0.500-inch thick or greater, with a minimum yield strength of 70 ksi. A pull force less than 20,000 pounds must be demonstrated. The pull force can be measured by the power-supply-gage reading (psi) times the cross-sectional area of the pull gun piston. The plate shall be restrained to prevent bulging of the edge opposite the hole.

Two sleeves from the first coil of stock that has been coated in one continuous processing run, and two sleeves made at the end of each production lot of sleeves shall be tested. In the event that coils from more than one coating-process run are employed in a production lot of sleeves, tests on sleeves fabricated from the first coil and last coil shall be required from each coating run. Failure of more than one sleeve per production lot shall result in rejection.

In the case of rejection, the manufacturer may resubmit using data taken from a sampling plan employing tests on production sleeves to qualify the lubrication coating thickness. The sampling plan tests will be conducted using 112-lb/yd or heavier rail.

APPENDIX A

TOOLING MATERIAL SOURCES

A.1 SLEEVES

Sleeves are available from Industrial Wire and Metal Forming Company, 1208 Andover Park, Seattle, Washington 98188, a sleeve producer licensed by The Boeing Company.

A.2 PULLER

The cold expansion process is conducted using the puller shown in figure 4, section 2.4. The puller is an ST-1350-C unit also available from Industrial Wire and Metal Forming Company. The unit is capable of 36,000-pound pull using a 10,000-psi hydraulic power supply.

A.3 HYDRAULIC POWER SUPPLY

A typical air-actuated hydraulic power supply is illustrated in figure 5, section 2.4. The units are available from the firm noted previously.

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