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Superseding ARP4146

Coiled Tubing - Titanium Alloy, Hydraulic Applications, Aerospace

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1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) specifically discusses five configurations of flexible tubing. The design data given will aid in design of coiled tube assemblies using Ti-3Al-2.5V cold worked, stress relieved (CWSR) tubing per AMS 4945. The configurations discussed should be compatible with pressure levels up to 8000 psi (55.2 MPa) upon completion of analysis for the actual stress and life requirement of the intended application. Formal qualification tests are recommended to verify satisfactory installation, clamping, and life of each unique design.

1.1 Purpose:

The purpose of this document is to provide data and information relative to design, fabrication, and installation of formed tubing made from titanium alloy. The formed tubing has the function of accepting relative motion between two points in a hydraulic system. The use of coiled tubes is encouraged in the design of hydraulic systems per MIL-H-5440 or pneumatic systems per MIL-P-5518. For information on design of coiled tube assemblies using CRES steel tubing, see ARP584.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP584	Coiled Tubing - Corrosion Resistant Steel, Hydraulic Applications
AIR1379	Prestressing (Autofrettaging) of Hydraulic Tubing Lines
AS4401	Separable Fittings, Tubing, Fluid Systems, 8000 psi, Qualification Test, Standard for
AS4467	Standardization Hydraulic Tube Walls
AS4076	Contractile Strain Ratio Testing of Titanium Hydraulic Tubing
AMS 4945	Titanium Alloy Tubing, Seamless, Hydraulic, 3Al-2.5V, Cold Worked, Stress Relieved

2.2 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-H-5440	Hydraulic System; Design, Installation, and Tests of Aircraft (General Specification for)
MIL-HDBK-5	Metallic Materials and Elements for Aerospace Vehicle Structures
AFWAL-TR-81-2066	Dynamic Seals for Advanced Hydraulic Systems
WADC 55-121	Study of Coiled Tubing for Aircraft Hydraulic Systems
WADC 57-507	Coiled Stainless steel Tubing, Part I Test Results
NADC-79217-60	Development of Small Diameter Hydraulic Coiled Tubing Technology, June 1981
NADC-87064-60	User’s Guide for Three Coiled Tube Design Programs - HELCOM, HELTOR, TRCOIL, and Supplementary Program - BENDS
NADC-87065-60	Advanced Coiled Tubing for Fluid Power Transmission, April 1987

3. CONFIGURATIONS:

Each configuration may be classified by one of the five styles described below.

3.1 Style A - Helical Torsion Configuration:

This configuration (Figure 1) typically consists of a 540° (1-1/2 coil) helical coil of tubing with a straight section projecting from each end of the coil. In actual application, if the coil is properly clamped at the points defined as "1" on Figure 1, the tube may have additional bends and straight lengths to allow aligning the end fittings with the interfacing fittings. In practice Style A may vary from 180° (1/2 coil) up to 900° (2-1/2 coils). This style is widely used within the aerospace industry to accept angular motion about a defined pivot point. Appendix A contains design data for Style A coiled tubes for 3000 psi (20.7 MPa) to 8000 psi (55.2 MPa), 1/2 to 2-1/2 coils and deflection up to 28°.

3.2 Style B - Torsion Tube Configuration:

This configuration (Figure 2) consists of three straight sections separated by two 90° bends. This is not a coiled tube configuration but is included in this document to present all standard configurations used to accept relative motion between two points. The middle straight section is twisted in operation, allowing one end to rotate about the centerline of the middle straight section. This configuration must be clamped between the bends and the fittings to remove bending stress from the fittings. This configuration is used to accept angular motion about a defined pivot point.

3.3 Style C - Helical Compression/Extension Configuration:

This configuration (Figure 3) consists of one or more coils coiled in a helix that accepts linear extension and compression. In order to align the coil fittings with the hydraulic component fittings, the use of specific transition bends from the tangent of the helix to the end fittings as described later in this document is recommended.

3.4 Style D - Tricoil Compression/Extension (C/E) Configuration:

This configuration (Figure 4) consists of three sets of helically wound coils connected by straight lengths to allow linear motion between the end fittings.

3.5 Style E- Oval Compression/Extension-(C/E) Configuration:

This configuration (Figure 5) is a special case of Style C where instead of coils being wound about a helix of constant diameter, the coils are oval shaped with straight lengths between semi-circular coils. This configuration has the advantage of being able to fit into shallow envelopes or to be installed coaxially around the outside of the moving hydraulic component for space efficiency. Another advantage of this configuration is that it requires fewer coils because of the large effective diameter of the coils.

4. MATERIAL PROPERTIES:

The recommended material is seamless titanium alloy tubing, Ti-3Al-2.5V in the CWSR condition in accordance with AMS 4945 or equivalent.

4.1 Basic Allowables:

Room temperature allowables for this material are:

a. Ftu, ultimate tensile strength (min): 125,000 psi (862 MPa)
b. Fty, yield tensile strength (min): 105,000 psi (724 MPa)
c. E, elastic modulus: 15,000,000 psi (103,421 MPa)
d. G, torsion modulus: 5,680,000 psi (39,162 MPa)
e. μ, Poisson's ratio: 0.32

4.2 Endurance Allowables:

In the design of the various configurations for a specific fatigue life, the use of the correct allowable stress is critical to the life of the design. Specific tests should be conducted on instrumented coils of the configuration to be used in order to determine the allowable number of mechanical flexure cycles at each stress level. The data may be put into the form of a Goodman constant life diagram in order to be easily used. Ideally, for Styles A and D, planar flexure of curved tubing would give equivalent fatigue data. For Style B, torsion flexure of straight tubing is recommended. For Styles C and E, torsion flexure of curved tubing or rotary flexure of curved tubing would give reasonable fatigue data. If the tests to determine fatigue life of specimens are conducted at room temperature, the stress allowable determined at each level of cycles should be reduced by an appropriate factor when designing coils which would have to operate in an environment at a higher temperature than the test temperature. A conservative method of correcting for property reduction at elevated temperature is to ratio the tensile yield stress at the elevated temperature to the tensile yield stress at the test temperature. Multiply the fatigue allowable at the test temperature times the ratio. Temperature correction data for several titanium alloys are published in MIL-HDBK-5.

Basic S-N curve type summation flexure and impulse fatigue data on straight tubing, bent tubing, and tube/fitting joints is required in sufficient quantity to establish a true performance scatterband to a 0.9 confidence level. This data may be obtained from the tube/fitting qualification test program similar to AS4401. From this data, modified Goodman (constant life) diagrams for the tube/fitting shall be prepared using the low end of the scatterband (i.e., that S-N curve which represents a 99.9% certainty that all performance data points that lie on or below the curve represent nonfailure conditions) as the basis for preparing the diagram.

4.3 Contractile Strain Ratio:

During tubing fabrication, crystallographic textures that develop in alpha titanium alloys such as Ti-3Al-2.5V CWSR as a result of cold reduction can cause significant anisotrophy or directional properties in finished tubing. These directional properties manifest themselves as excessive thinning or rupture of the tube wall on the outer bend radius during bending. Other manifestations are reduced yield and burst strength under internal pressurization and reduced fatigue life in pressure-flexure testing. The material properties to give a balance of performance between the extremes may be determined using a test property called contractile strain ratio (CSR). AS4076 (referenced in AMS 4945) gives a method for determining the CSR.

5. STRESS ANALYSIS:

There are a number of methods that may be used to analyze the total stresses at critical points in the coils. Technical Reports WADC 55-121 and 57-507 give classical techniques that may be applied to design algorithms for any material and configuration. Technical Report NADC-79217-60 derives the equations and gives flow charts for algorithms which may be applied to Styles A, B, C, and D. Technical Report NADC-87064-60 further transforms these algorithms into Fortran language computer programs. The programs use the Von-Mises Distortion Energy Failure Theory for loading in multiple axes. Finite Element Analysis (FEA) is another technique for stress analysis of the sometimes irregular configurations required of coiled tubing. The particular brand of FEA software should have bar elements for possible nonlinear cases.

6. FITTINGS:

The following fitting systems have been tested or used with coiled tube installations successfully:

a. MS flareless
b. Flareless with brazed or swaged sleeve
c. Dynamic beam seal with internal swaging
d. Dynamic beam seal with external swaging
e. Cryogenic swaged

These currently used fitting systems will work with coiled tubing under the following conditions which must be considered in the design. The stresses at the end of the fittings should be separately analyzed as they may be higher than those in the coils. Technical Report NADC-87065-60 gives methodology for stress analysis at the end of fittings and in transition bends using a combination of FEA and conventional computation techniques. Combinations of torsion and linear loading should be avoided unless specifically addressed in qualification testing of coiled tube designs.

7. FABRICATION:

7.1 Style A:

Style A may be fabricated using one of several methods of forming the coils. Use of mandrels or rollers which closely match the tubing outer diameter is recommended in order to control flattening or ovality of the tube in the curved sections after forming. For Ti-3Al-2.5V CWSR material the final ovality should not exceed 3% using the following definition:

$$\text{OVALITY} = \frac{(\text{MAXOD} - \text{MINOD}) \times 100}{\text{NOMINALOD}} \qquad \text{(Eq. 1)}$$

7.1.1 Conventional Tooling: The conventional die block which contains a semicircular shaped groove around 180 to 270° of its external surface must be replaced by a similar block containing a groove which spirals through 600° (1-2/3 turns). As this spiral die block turns, it must be free to shift along its axis, or the feed block must move relative to the spiral die to accommodate the lead of the spiral. This tooling is discussed in more detail in Technical Report WADC 55-121. The feed block (which supports the unbent tube) must be tilted to an angle approximately equal to the helix angle, which can be adjusted to produce the correct pitch (typical spring winding technique).

7.1.2 Spiral Mandrel: Another type of tooling which may be used for Style A is a spiral mandrel that moves along its axis as it is turned to form the pitch of the coils. This type of tool is shown on Figure 6. This type of tooling may be used for all styles of flexible tubing that use coils. It consists of a machined mandrel with reduced coil diameter to compensate for material springback and reduced pitch to compensate for pitch springback after forming. Two details that require particular attention are the method of clamping the formed end of the tubing to the mandrel and the provision of adequate torque multiplication to keep force required for forming constant and well within human factors limitations. Tubing greater than 3/8 in (9 mm) diameter should be formed using a powered tool.

The following equation may be used to determine the diameter of the mandrel to use for a required coil diameter after springback. This equation has an accuracy of 2% of the coil diameter.

$$Da = \frac{1.02 \times R}{\left(\frac{R}{Ds} - R\right) + \left(1.85 \times \frac{Ftu}{E}\right)} - Do \qquad \text{(Eq. 2)}$$

where:

$$R = \frac{\sqrt{2}}{2} \times \sqrt{Do^2 + Di^2}$$

Da = arbor diameter
Ftu = ultimate tensile stress allowable
E = modulus of elasticity
Do = tubing OD
Di = tubing ID
Ds = coil OD

Other factors that will affect the accuracy of the final coil diameter are the consistency of the torque applied during forming and variation of material properties from lot to lot of material.

7.1.3 Other Tooling: Other types of tooling may be used to form helical coils. These types are based upon the positioning of rollers which deflect the tubing as it is fed into the rollers through a guide. This type of tooling is normally used for fabrication of springs and is available in the form of coiling machines from manufacturers. The machines range in complexity and capability from manually adjusted to microprocessor controlled designs. In a survey conducted in 1985, none of the machines surveyed were immediately acceptable for use in forming coiled tubing. Two principal problems were that the machines required continuous roll supply stock and used shear methods to cut-off the stock at the end of a forming cycle. However, with development, these sophisticated machines could be used for forming coiled tubing with the advantage of being adaptable to a wide range of tube diameters, coil diameters, and pitches. This is contrasted to the conventional tooling based on mandrels or machined helixes to form the coils. Coil forming machines and their concepts of operation are more fully discussed in Technical Report NADC-87065-60.

7.2 Style B:

Style B may be fabricated using conventional bending equipment normally used for bending tubing.

7.3 Style C:

Style C may be formed using any of the tooling described for Style A in 7.1.2 and 7.1.3.

7.4 Style D:

Style D may be formed using any of the tooling described in 7.1.1 through 7.1.3.

7.5 Style E:

Style E may be formed using tooling described in 7.1.1 or 7.1.3.

7.6 Surface Finish:

During fabrication and handling the surface finish of the tubing inner diameter and outer diameter should be protected from scratches and dents. Lubrication of mandrels may be required to prevent linear scratches in the tube wall during forming.

8. AUTOFRETTAGE:

This is a technique that is used to reduce ovality and improve fatigue life of the tubing by pressurizing the tubing until the stress at the inner wall of the tubing is in the plastic range. By applying internal pressure in this manner ovality is reduced by forcing the tube to assume a shape closer to the original diameter. Also, after removal of pressure, the inner wall has a residual compressive stress that reduces the effect of minor imperfections and irregularities in the inner tube wall. Tests by major airframe manufacturers demonstrated increased fatigue impulse life after autofrettage of tubing. These benefits are a function of the amount of ovality with little advantage when ovality is less than or equal to 2%.

Autofrettage will not compensate for tooling that is worn or does not support the tube diameter during forming. It is probably more effective on "thin wall" tubing. Thin wall tubing here is defined as having a wall thickness set by the minimum burst pressure requirement. Wall thickness meeting a burst pressure of at least four times operating pressure will result in fewer coils than tubing with lower burst pressure design. AIR1379 has further discussion and recommendations concerning autofrettage.

When autofrettaging or applying proof pressure to a coiled tube assembly, the tube ends should be clamped or restrained to maintain the critical interface dimensions relative to the mating tubing in the aircraft.

9. INSTALLATION:

A space layout and geometry study will indicate which style configuration can be used for each application. The layout may be used to determine maximum deflection of coiled tubes during operation and to establish maximum coil diameters. Consideration must be given to the deflection imparted to the coil if one end of the hydraulic component is disconnected and its weight is supported by the coiled tube. Also, it is necessary to determine or estimate other factors such as: (1) misalignment when the component operates or, (2) damaging loads if the installation is subject to use for standing or a hand hold by maintenance personnel. A mockup of the installation can be a valuable aid in identifying the portions of the tubing which move and help in location of clamps.

9.1 Style A Installation:

Style A accommodates oscillating motion about a pivot. The centerline of the helix should be located close to or upon the centerline of the major pivot axis. Figure 7 shows the maximum limits established by ARP584 for CRES steel tubing, but should also be reasonable limits for titanium tubing. The helix should be located as close as possible to the moving component to minimize the effects of misalignment. The coil should be designed for rotation of 10 to 20% more than the nominal deflection to allow for misalignment or rotation of the actuator during operation. The percentage used should be equal to or greater than the actual values calculated from geometry and installation tolerances. A symmetrical installation about either side of the actuator using right and left hand pitch in the helixes will result in a balance of rotational forces that is desirable. When self-aligning bearings are used on the actuator mounting points, restrict actuator rotation torsionally by mechanical means such as special washers or lugs on the bearing strap. When designing an installation where several coils are installed in close proximity to one another, additional clearance over those typically applied to conventional tubing installations must be used to prevent interference of the tubes due to normal fabrication tolerances and springback variation from coil to coil. When the number of coils is even such as one or two coils, the moment arms B fall approximately 180° from each other. In this case, it is required to clamp at least one moment arm so as to force the coil to deflect about the actuator pivot centerline. Figure 1 has an example of this requirement. If the additional clamping is not provided, the geometry results in compression and extension loads into the coil and fittings which are not well defined and could lead to fitting leakage or early fatigue failure of the tube.

9.2 Style B Installation:

Style B accommodates oscillating motion about a pivot. The centerline of the tube should be located concurrent with the centerline of the pivot. The torsion tube may be displaced in either direction. The torsion tube will require tubing guides that will allow the tube to rotate but not deflect such that bending is imposed during flexure. The guides shall be located within 0.25 in (6 mm) of the tangency point to the radius, and a third guide shall be installed at the midpoint on the larger sizes (0.5 in (13 mm) diameter and up). Satisfactory adjustments shall be incorporated at the guide and tube attachment points to stay within the installation tolerances. It is suggested that the tube be attached to the connecting fittings before the guide block is installed. This will indicate if any tube deflection or fitting misalignment occurs. With Style B, it is not permitted to route the tubing in a manner in which any fitting centerline is parallel to the centerline of the tube in torsion. If fittings are located with centerlines parallel to the centerline of the tube in torsion, the fittings are subject to chronic loosening and leakage each time the actuator is operated. Figure 2 gives an example of this poor design.

9.3 Style C Installation:

Style C may be designed using the FORTRAN language design programs described in Report NADC-87064-60. The use of the HELCOM program requires that the working stroke of the coiled tube be equal to 0.5666 times the actuator stroke from fully compressed to fully extended. The program BENDS may be used to design the transition bends from the end of the helix to the hydraulic fittings on each end. Appendix A in Report NADC-87065-60 provides a methodology for stress analysis of the transition bends and the area at the end of the fitting using FEA and traditional computation. It is desirable to clamp Style C using elastomeric block clamps at each end to alleviate bending loads in the end fittings. Rise and fall in the actuator can be tolerated but should be considered in stress analysis at the end fittings. Program HELCOM has an option to compensate for stress due to lateral deflection of the coiled tube. As shown in Figure 3, two assemblies of Style C may be installed about a common centerline to occupy less space. The outer coil should be the high pressure system if one of the coils is low pressure and one is high pressure.

9.4 Style D Installation:

The tricoil configuration is designed for extension only corresponding to windup of the coils. Therefore, the coils will be at free position when the distance from the moving component to the interface is a minimum. The fitting locations should be dimensioned for the free position of the coil. Simple loop or block clamps should be used to maintain separation of two Style D configurations installed in close proximity to each other. The coiled tube should be designed for the lowest spring rate possible in the space available in order to reduce the axial loads imposed upon the end fittings. This means that the coils are designed for a lower allowable stress than that corresponding to the specific fatigue life required of the design. Report No. NADC-87065-60 describes tests of ten assemblies of 3/8 in (10 mm) diameter tubing in the tricoil configuration which were subjected to 800,000 one-half stroke cycles and 200,000 full stroke cycles without any problems with end fittings or coil design.

9.5 Style E Installation:

This design can be designed to install concentrically with the moving component and nested with another coil if desired. This type of installation is depicted in Figure 5. It is recommended that the coils be clamped at the extreme ends of the coils as shown in order to control deflection and to support the weight of the coil against vibration or acceleration loads. If two coils are nested, the outer one should be used for the highest pressure required by the application. For example, if the two coils are carrying system operating pressure and system return pressure, the outer coil should be the assembly designed for system operation pressure. The larger outer coils will have low mechanical stress to sum with the higher stress due to system pressure, whereas the smaller inner coils will have higher mechanical stress to sum with lower stress due to return pressure.

10. VIBRATION DAMPING:

As with springs, coiled tubes have natural frequencies and can be excited by induced vibration. It is recommended that each installation be subjected in situ to a spectrum of the frequencies and acceleration for the application. Each coiled tube should have an accelerometer mounted and data recorded in each axis. Analysis and test may show that the tube natural frequency and inherent damping may not require any addition damping. If additional damping must be considered the following experimental techniques were tested on coiled tubes and reported in NADC-87065-60. Techniques that can be adapted for damping coiled tubing are as follows.

10.1 CRES Wire Rope:

CRES wire rope is available in a choice of diameters and number of wires in the bundle. The number of wire strands should be the maximum number available in a given wire rope size. This makes the wire rope more flexible. The wire rope may be attached to the coiled tube in a manner as shown in Figure 8. Because the wire rope is flexible it can be installed to deflect in the direction of motion of the coiled tube and yet provide damping by the friction between strands of wire. The damping force and spring rate of the damping installation will have to be determined experimentally.

10.2 Ties and Loops:

If two coiled tubes deflect the same with respect to one another, the natural frequency of each coil can be changed by tying the coils together with plastic ties similar to those used for tying bundles of wire harness together. The plastic material used for the ties should be resistant to cracking and embrittlement with exposure to ozone, sunlight, hydraulic fluid, fuel, solvents, rain water, and extremes of ambient and system temperature. The ties should be part of the qualification test for the coiled tube installation to verify acceptable wear and damping over the expected service life of the installation.

10.3 Commercial Wire Rope Damper:

Wire rope damping assemblies as shown in Figure 9 are available which can be designed for specific damping. This type of damping device was tested and reported in NADC-87065-60 but did not seem to be as effective as one or two individual wire loops. The mass of the bar tying the wire rope loops together may have been a factor.

11. DESIGN AIDS:

11.1 Nomograms:

Report NADC-79217-60 has nomograms for design of coiled tubes in styles C and D for 3/16 in diameter tubing in Ti-3Al-2.5 CWSR material.

11.2 Computer Programs:

Report NADC-87064-60 describes three FORTRAN language programs that may be used to design coiled tubes. The programs are available upon request from the Naval Air Development Center, Warminster, Pennsylvania. The programs give feasible designs for Styles A, C, and D.

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SAE SUBCOMMITTEE A-6C, FLUID POWER DISTRIBUTION ELEMENTS OF
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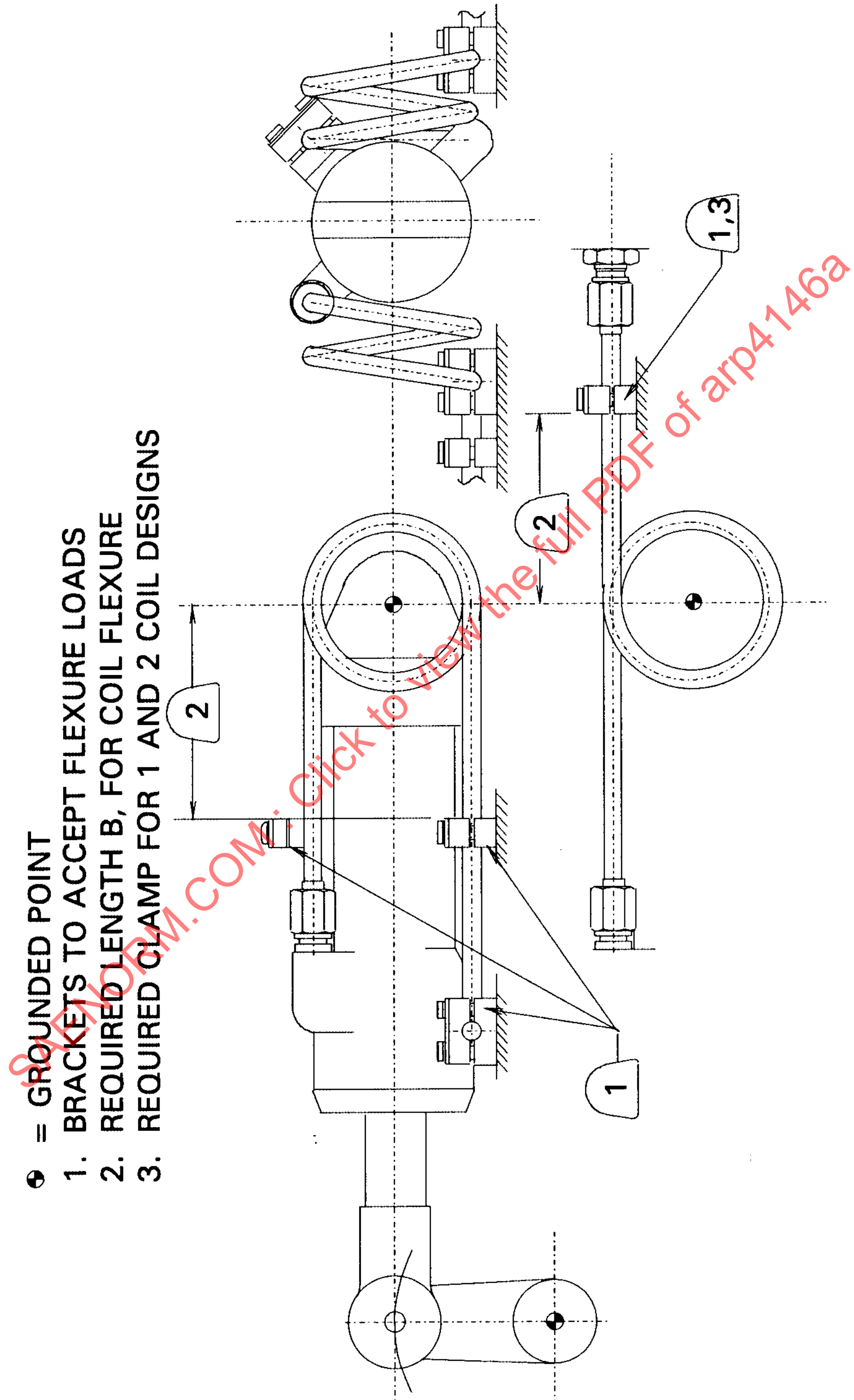


FIGURE 1 - Style A - Helical Torsion Configuration

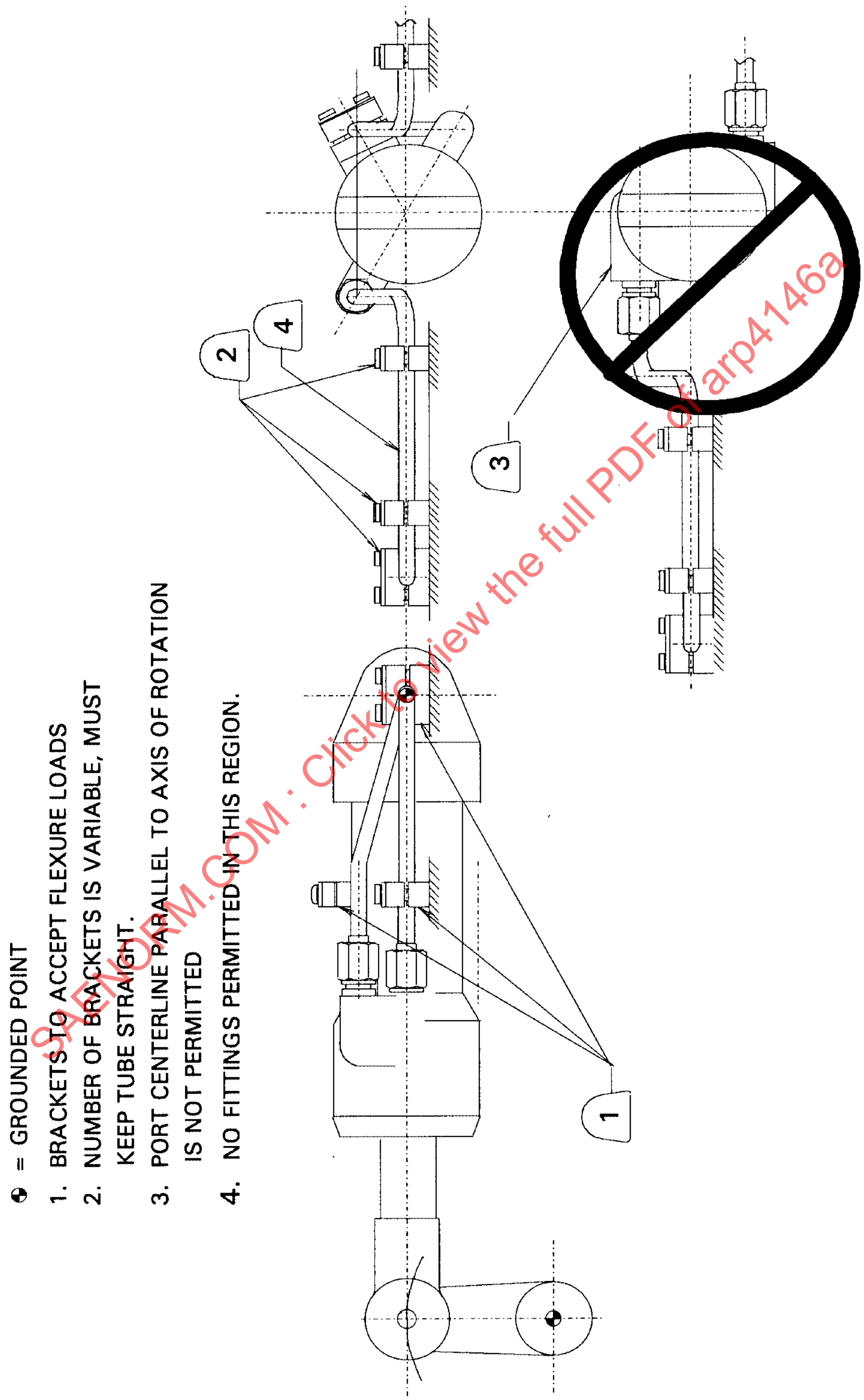


FIGURE 2 - Style B - Torsion Tube Configuration

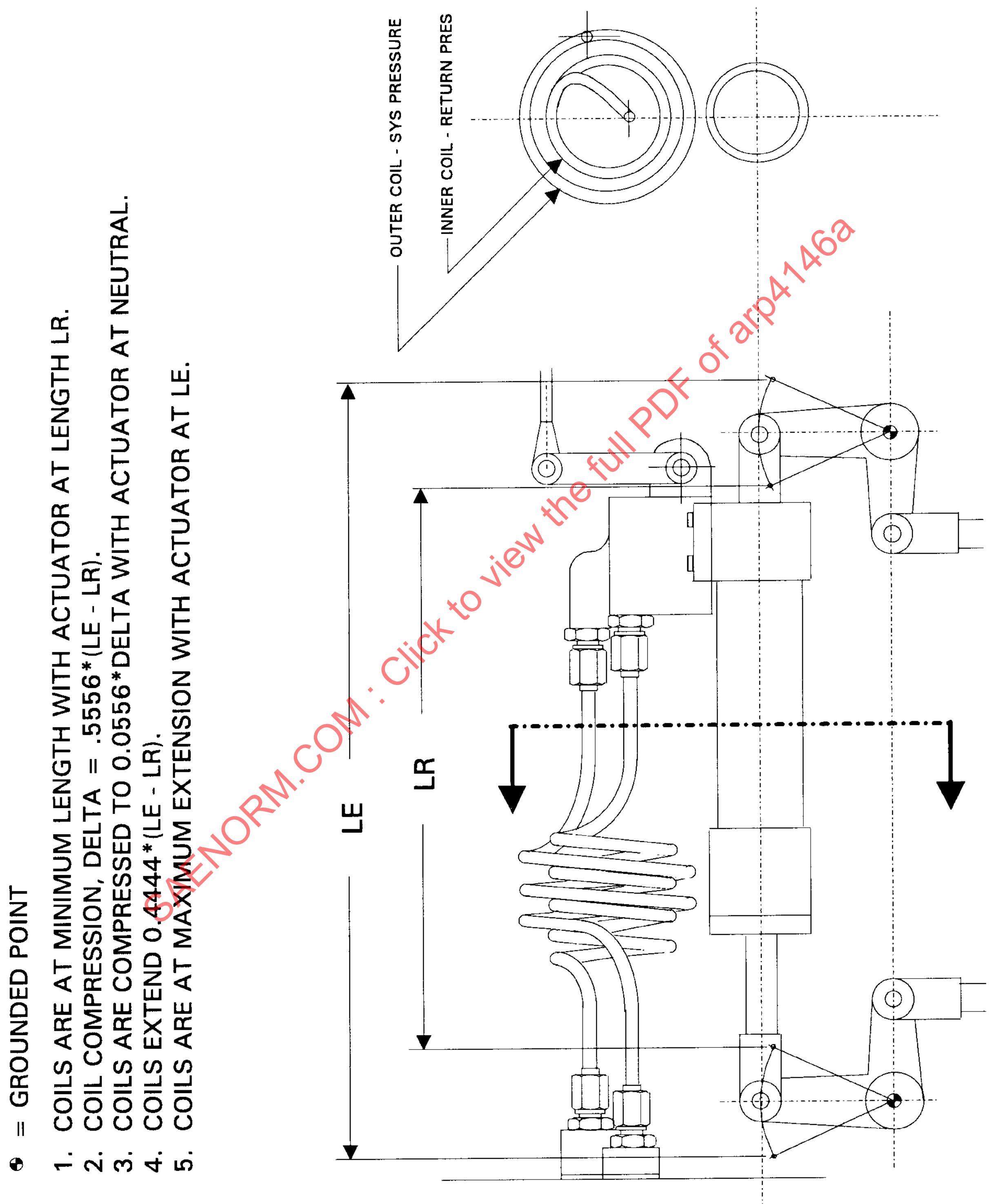


FIGURE 3 - Style C - Helical Compression/Extension Configuration

● = GROUNDED POINT

1. COILS ARE AT FREE POSITION WITH ACTUATOR AT LENGTH LR.
2. COIL ARE AT MAXIMUM DEFLECTION WITH ACTUATOR AT LENGTH LE.
3. FOR THIS APPLICATION, COIL STROKE = (LE - LR)/2.
4. FOR CYLINDER FIXED, ROD MOVING OR ROD FIXED, CYLINDER MOVING, THE STROKE = LE - LR.

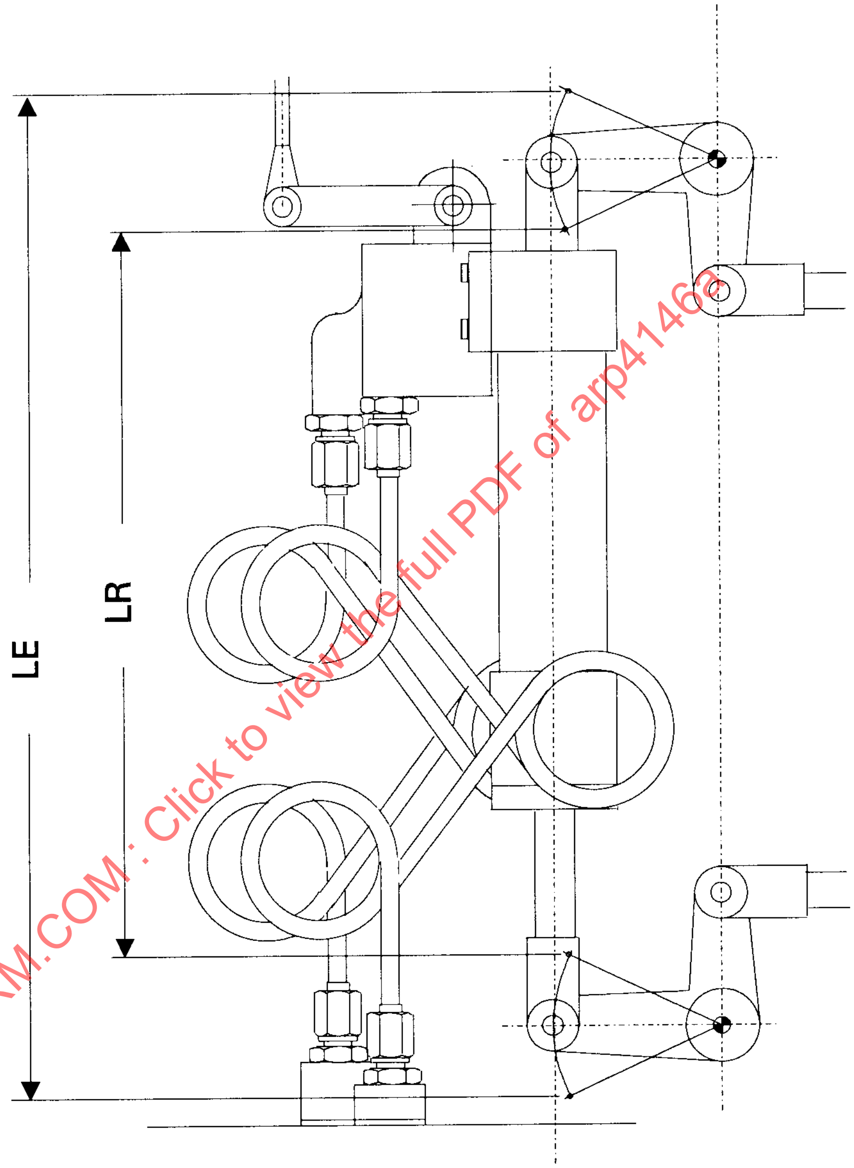


FIGURE 4 - Style D - Tricoil Compression/Extension Configuration

● = GROUNDED POINT

1. COILS ARE AT MINIMUM LENGTH WITH ACTUATOR AT LENGTH LR.
2. DELTA = COIL COMPRESSION. DELTA = 0.5556 * (LE - LR).
3. COILS ARE COMPRESSED TO 0.0556 * DELTA WHEN ACTUATOR IS AT NEUTRAL.
4. COILS EXTEND 0.4444 * (LE - LR).
5. COILS ARE AT MAXIMUM LENGTH WITH ACTUATOR AT LENGTH LE.

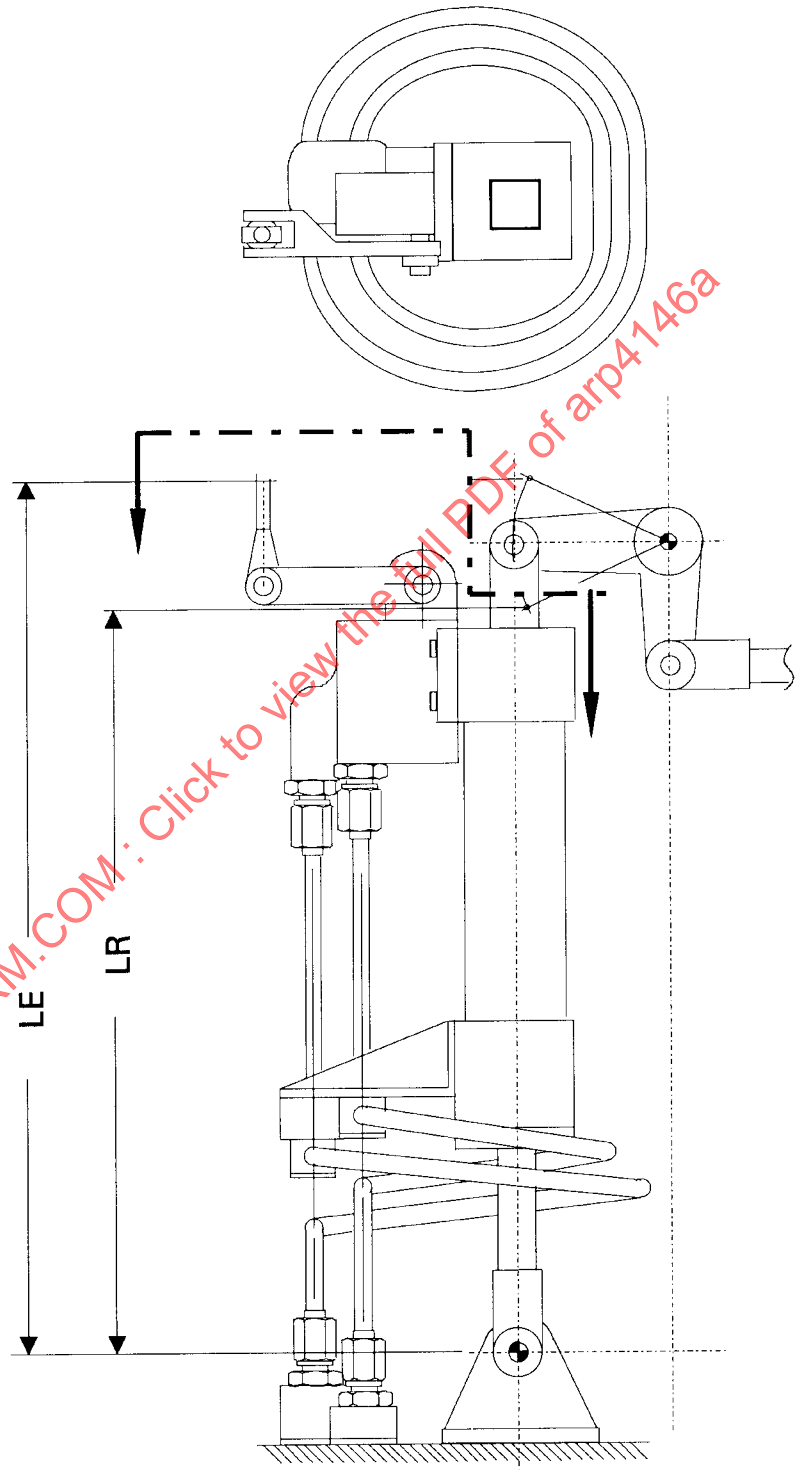


FIGURE 5 - Style E - Oval Helical C/E Configuration

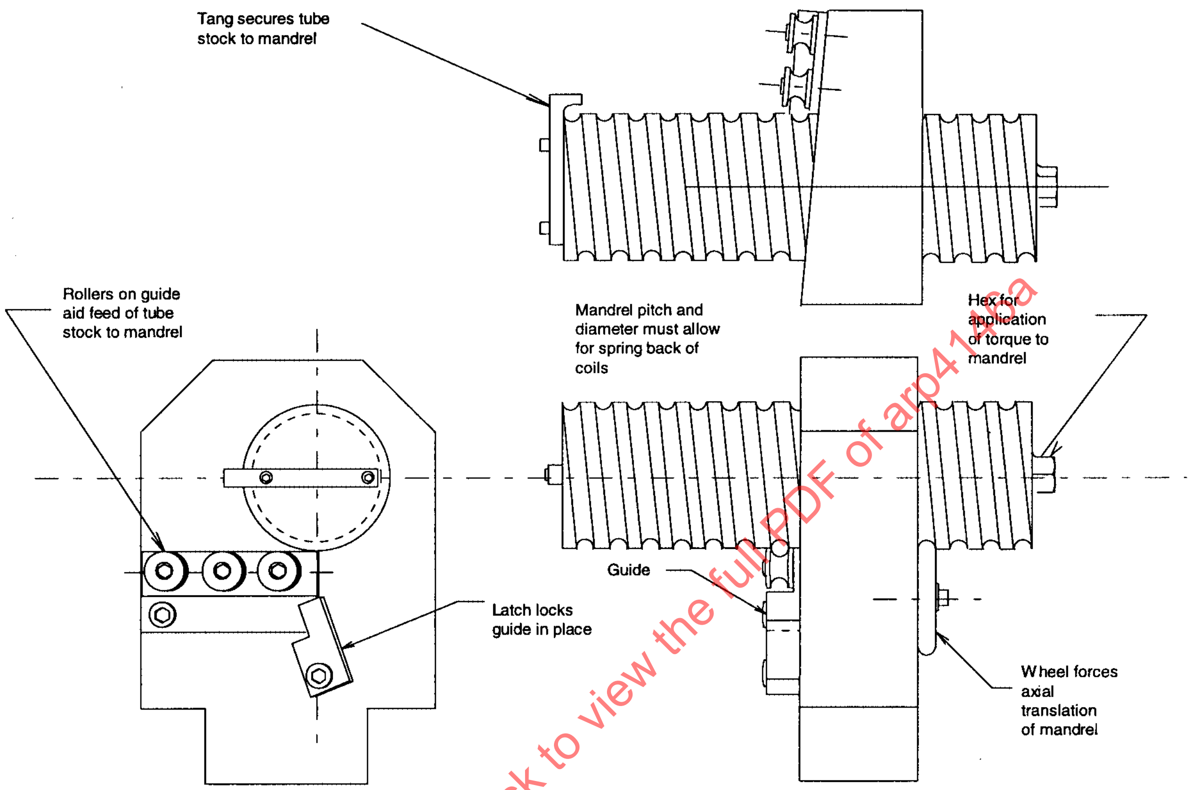
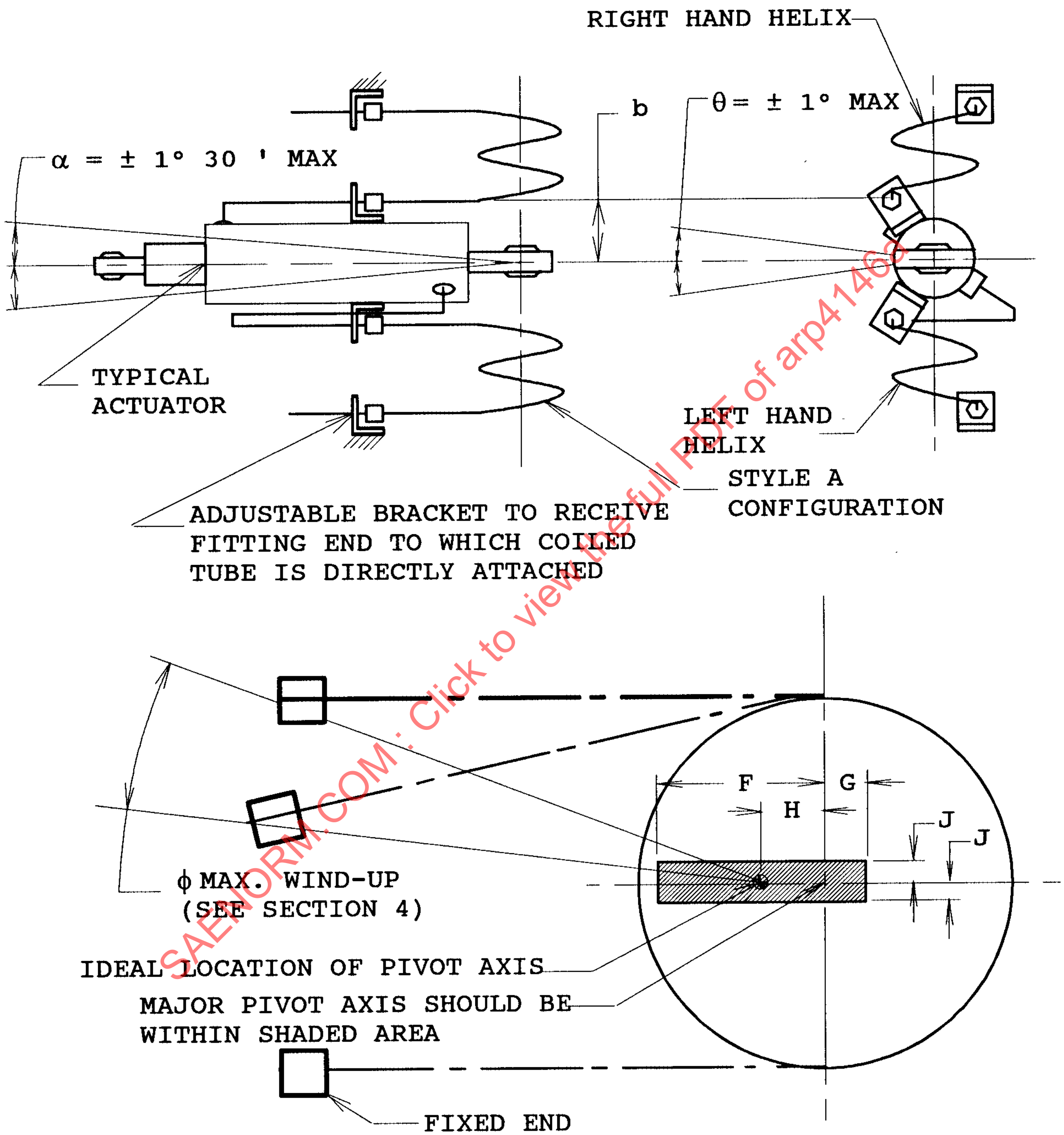


FIGURE 6 - Spiral Mandrel Coiling Tool



F		G		H		J	
IN.	MM	IN.	MM	IN.	MM	IN.	MM
1.00	25.4	0.25	6.4	0.375	9.5	0 TO 0.125	0 TO 3.2

FIGURE 7 - Centerline Limits for Style A Installation

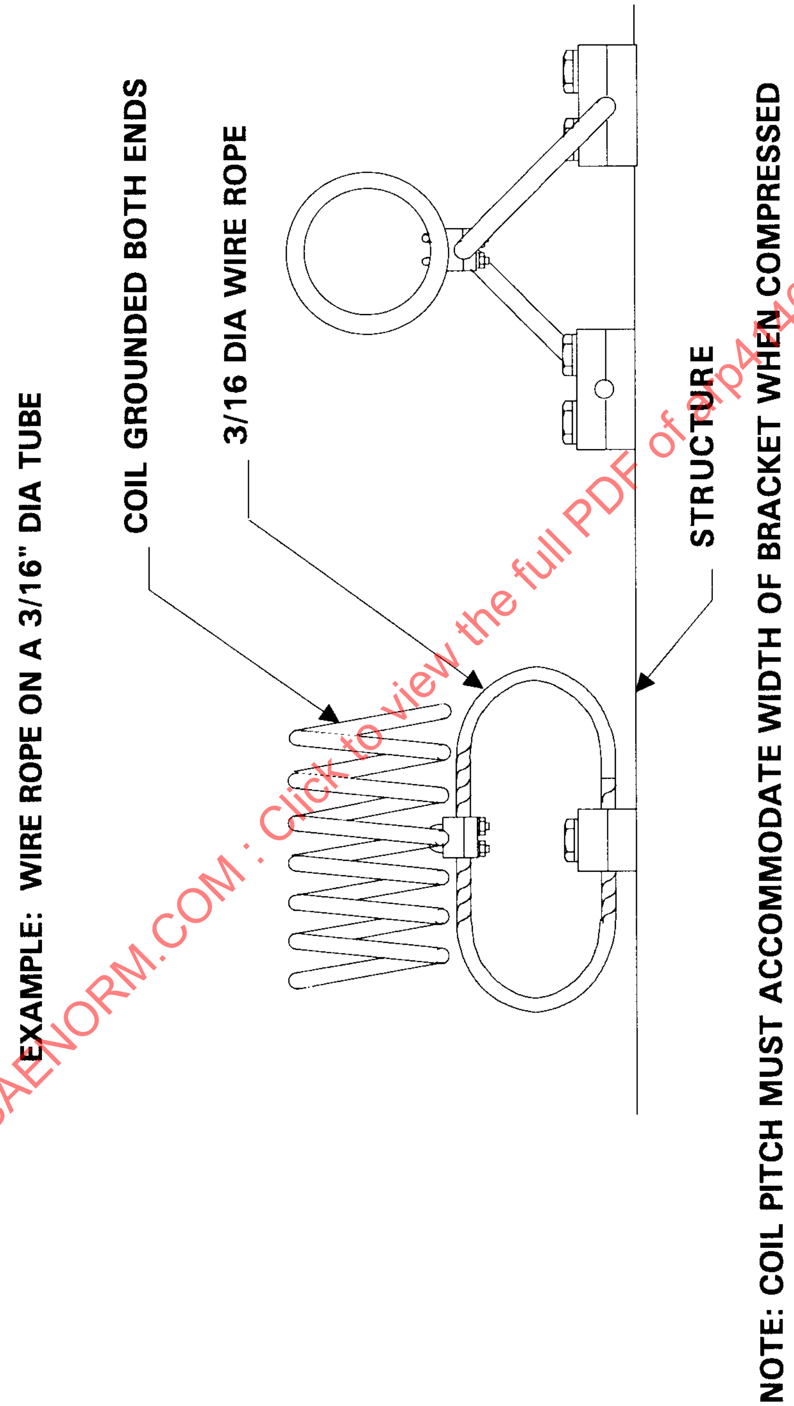


FIGURE 8 - CRES Wire Rope Damper

FIGURE 9 - Commercial Wire Rope Damper

APPENDIX A
DESIGN DATA FOR STYLE A CONFIGURATION

A.1 DESIGN SPECIFICATIONS:

A.1.1 Basis:

The coiled tube dimensions in the following figures were designed using the FORTRAN language computer program HELTOR which is published in NADC-87064-60 with enhancements to allow direct computation for accumulated fatigue due to impulse and endurance cycling. The resulting designs have not been tested formally and should be qualified either with the actuator installation or in specific qualification tests.

A.1.2 Tube Wall Thickness:

The tube wall shown is the minimum thickness required. Any nominal wall thickness may be used providing that the production minimum thickness is not less than the minimum shown. In all cases except the 8000 psi (55.2 MPa) designs, the tube wall thickness corresponds to the standard wall thicknesses published in AS4467. In the case of the 8000 psi (55.2 MPa) designs, the wall thicknesses required are greater than those in AS4467 in order to provide a consistent design at the required specifications.

A.1.3 Computed Fatigue Life:

Fatigue analysis was performed to show no failure at four times the endurance and impulse cycles below:

Operating Pressure: 3000, 4000, 5000, 8000 psi (20.7, 27.6, 34.5, 55.2 MPa)
Impulse Pressure: 1.5 times Operating Pressure
Endurance Life: 100,000 cycles @ 100% deflection (windup only)
Impulse Life: 200,000 cycles 100 psi (689 kPa) to 1.5 x Operating Pressure

$$\lambda = \sum\left(\frac{4n}{N}\right) < 1 \qquad \text{(Eq. A1)}$$

where:

λ = Cumulative fatigue damage

In addition, the 24°, 2-1/2 coil version of each tube size for each design pressure was analyzed to show no failure at four lifetimes of the following spectrum which was a generic spectrum derived in AFWAL-TR-81-2066 for digital fly-by-wire flight control actuators. The spectrum was obtained by analysis of flight test data for the F-16, F-111, and NASA Fly-By-Wire F-8 aircraft. Because of mathematical consistency of the design program, all of the designs are designed for the following spectrum with a scatter factor of four:

TABLE A1

Deflection - %	Cycles (One Lifetime)
1	181,000,000
2	17,500,000
10	1,250,000
50	200,000
100	50,000

A.2 USE OF DESIGN DATA FIGURES:

A.2.1 Coil Dimensions:

In order to make this document as generic as possible, no specific tube fitting designs are assumed. Note in Figure A1, the dimension B for the moment arm of the coiled tube is established based upon the fatigue analysis. For an application, the appropriate length of tube must be added for the tube fitting system being used. A moment arm less than dimension B will shorten the endurance life of the coiled tube.

In Figures A2 through A5, the dimension A from the coil centerline to the standard bend to establish parallel moment arms is based upon the following equations which consider the overbend to form the bend and avoid interference between the outer diameter of the coil and the bend mandrel.

$$\text{Wrap} = \text{Rc} \times \left(1 + 15 \times \frac{\pi}{180}\right) \quad \text{(Eq. A2)}$$

$$\text{P} = .02947 + 1.31928 \times \text{Do} \quad \text{(Eq. A3)}$$

$$\text{A} = \frac{\text{Dm}}{2} + \frac{5 \times \text{Do}}{6} + \text{Wrap} \quad \text{(Eq. A4)}$$

$$\text{B} = \text{A} + \text{Do} \quad \text{(Eq. A5)}$$

$$\text{C} = \text{P} \times \frac{2 \times \text{A} + \text{Dm}}{2 \times \text{Dm} + \text{En} - 0.5} \quad \text{(Eq. A6)}$$

A.2.1 (Continued):

where:

Do = nominal tube outer diameter
Dm = coil mean diameter
Wrap = allowance for overbend
P = coil pitch
A = length from coil centerline to Rb tangent
B = moment arm
C = normal distance between straight portions of moment arms
Rb = standard 3D bend radius
Rc = Dm/2

A.2.2 Design Data (Figures A2 through A5):

Each figure is five pages. There is a figure for each design pressure, 3000, 4000, 5000, and 8000 psi (20.7, 27.6, 34.5, and 55.2 MPa). Each sheet of each figure contains the minimum tube wall, mean coil diameter, pitch, dimensions A, B, C, and D; the weight of the tube, and the deflection force required for each combination of tube outer diameter, deflection, and number of coils. The first sheet of each figure contains data for 1/4 and 3/8 in (6 and 10 mm) tube diameters. The second sheet of each figure contains data for 1/2 and 5/8 in (13 and 16 mm) tube diameters. The third sheet of each figure contains data for 3/4 in (19 mm) tube diameters.

A.2.3 Example of Use of Design Data Figures:

Assume the following design case:

Operating pressure = 4000 psi (27.6 MPa)
Deflection = 9°
Tube diameter = 3/8 in (6 mm)

50,000 cycles full stroke deflection
Installation requires both tube fittings to be adjacent

1. The required endurance of 50,000 cycles is well within the 100,000 cycle computed design life for coil designs in this document.

2. Referring to Figure A3 for 3/8 in (10 mm) tube diameter, 4000 psi (27.6 MPa), for 1/2, 1-1/2, and 2-1/2 coils, the Weight versus Deflection graph shows that the 1-1/2 coil configuration is the lightest choice for 9° deflection. (To obtain data for odd degrees, average the values for the even degree data below and above the odd degree requirement.)

TABLE A2 - Weight~lb (N)

En	8°	10°	9°
1/2	0.131 (0.58)	0.171 (0.76)	0.151 (0.67)
1	0.106 (0.47)	0.140 (0.62)	0.123 (0.55)
1-1/2	0.100 (0.45)	0.112 (0.50)	0.106 (0.48)

A.2.3 (Continued):

3. The Force versus Deflection graph shows for 1-1/2 coils, 9° that a limit load of 11.8 lb (52.3 N) is required at full deflection.

4. Use of the tabular data gives the rest of the information needed:

   Rc = 2.63/2.72 in (66.8/69/1 mm)
   A = 3.05 in (77.4 mm)
   B = 3.98 in (101.3 mm)
   C = 1.39 in (35.4 mm)
   D = 5.26/5.39 in (133.6/136.9 mm)
   P = 0.49 in ± 0.04 in (12.4 mm ± 1.0 mm)

Of course the information for 10° from the printed data could be used for conservative design as well.

For applications where the design requires the number of coils to fall between one of the printed cases, interpolation may be used to establish the resultant coil dimensions. Assume 3.8 in tube, 4000 psi, 12° full deflection required.

If analysis of the installation determined that 1.63 coils would provide the correct angular relationship of the moment arms B to mate with the attach points of the fixed tubing, then the interpolation process for 12° deflection would be between 1.5 coils and 2 coils as follows:

$$B_{1.5} = 7.42\ (188.5)$$
$$B_2 = 4.45\ (113.0) \quad \text{(Eq. A7)}$$

$$\frac{7.42 - B_{1.63}}{7.42 - 4.45} = \frac{2 - 1.63}{2 - 1.5} \quad \text{(Eq. A8)}$$

$$B_{1.63} = 5.22\ (132.6) \quad \text{(Eq. A9)}$$

A.2.3 (Continued):

To compute dimension C:

$$
\begin{aligned}
A &= 3.05\ (77.4) \\
Dm &= 5.26\ (133.6) \\
En &= 1.63 \\
P &= 0.49\ (12.4)
\end{aligned}
\qquad \text{(Eq. A10)}
$$

$$C = P \times \frac{2 \times A + Dm}{2 \times Dm + En - 0.5} \qquad \text{(Eq. A11)}$$

$$C_{1.63} = 1.59 \text{ in } (40.4) \qquad \text{(Eq. A12)}$$

Figure A1 following shows the location and of the dimensions required to define the tube configuration.

Figures A2 through A5 follow with data for Style A coiled tubes for 3000, 4000, 5000, and 8000 psi (20.7, 27.6, 34.5, and 55.2 MPa) operating pressure, 1/2, 1, 1-1/2, 2, 2-1/2 coils, and deflection up to 28°.

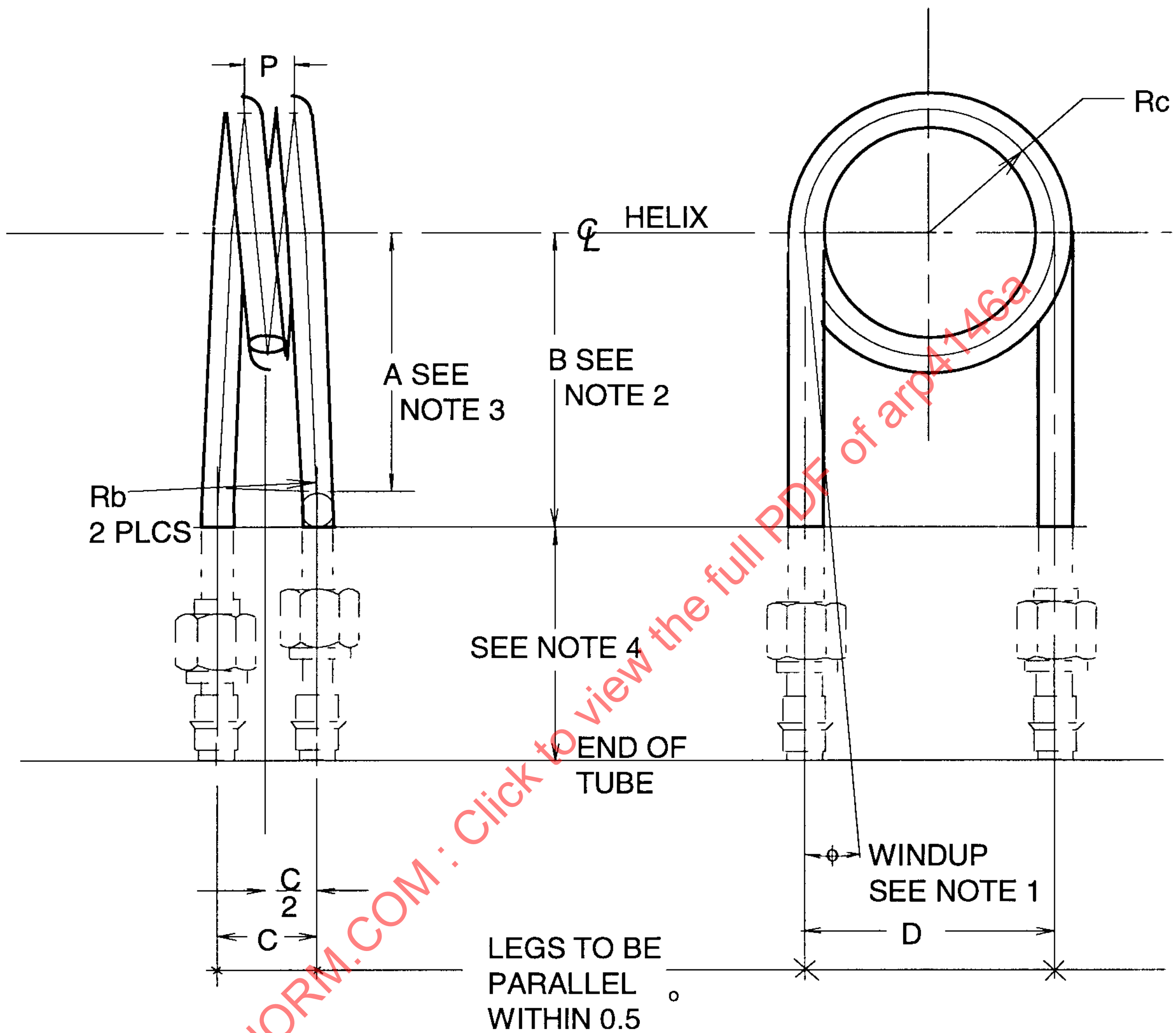
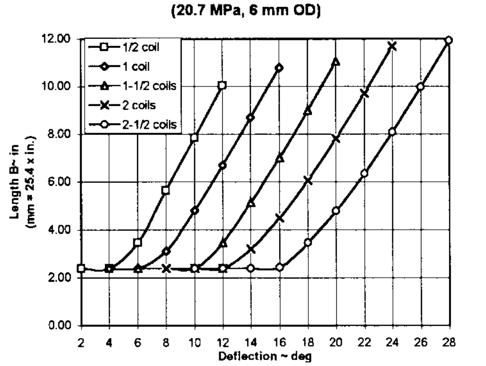


FIGURE A1 - Style A Design Dimensions

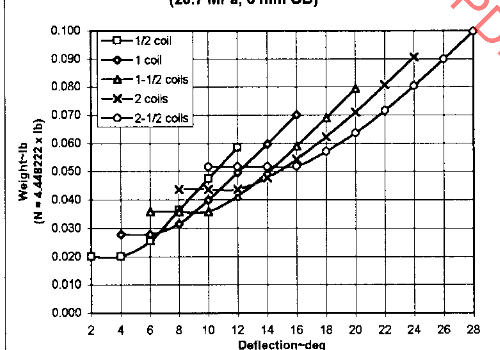
	φ1/4" x .022 3000 psi					Rc = 2.00/2.09 in.					Pitch = 0.33±0.03 in.					D = 4.00/4.19 in.									
	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2	2.15	2.40	0.00	0.020	5.8																				
4	2.15	2.40	0.00	0.020	5.8	2.15	2.40	0.75	0.028	6.2															
6	2.15	3.48	0.00	0.026	5.5	2.15	2.40	0.75	0.028	6.2	2.15	2.40	0.93	0.036	5.5										
8	2.15	5.66	0.00	0.036	3.7	2.15	3.12	0.75	0.032	5.9	2.15	2.40	0.93	0.036	5.5	2.1547	2.40	1.11	0.04	5.8					
10	2.15	7.85	0.00	0.048	2.8	2.15	4.81	0.75	0.040	4.2	2.15	2.40	0.93	0.036	6.9	2.15	2.40	1.11	0.044	5.8	2.15	2.40	1.29	0.052	5.4
12	2.15	10.05	0.00	0.059	2.2	2.15	6.70	0.75	0.050	3.2	2.15	3.47	0.93	0.041	5.5	2.1547	2.40	1.11	0.04	6.9	2.1547	2.40	1.2853	0.052	5.4
14						2.15	8.71	0.75	0.060	2.5	2.15	5.13	0.93	0.050	4.0	2.15	3.20	1.11	0.048	5.8	2.15	2.40	1.29	0.052	6.3
16						2.15	10.79	0.75	0.070	2.1	2.15	7.00	0.93	0.059	3.1	2.1547	4.51	1.11	0.05	4.4	2.1547	2.44	1.2853	0.052	7.1
18											2.15	8.99	0.93	0.069	2.4	2.1547	6.07	1.11	0.06	3.5	2.1547	3.47	1.2853	0.057	5.5
20											2.15	11.05	0.93	0.080	2.0	2.1547	7.83	1.11	0.07	2.8	2.1547	4.78	1.2853	0.064	4.2
22																2.1547	9.72	1.11	0.08	2.3	2.1547	6.34	1.2853	0.072	3.3
24																2.1547	11.70	1.11	0.09	1.9	2.1547	8.09	1.2853	0.080	2.7
26																					2.1547	9.98	1.2853	0.090	2.2
28																					2.1547	11.94	1.2853	0.100	1.9

	φ6 mm x 0.56 mm 20.7 MPa					Rc = 50.8/53.1 mm					PITCH =8.4±0.8 mm					D = 101.6/106.4 mm									
	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2	54.7	61.1	0.0	0.1	25.6																				
4	54.7	61.1	0.0	0.1	25.6	54.7	61.1	19.0	0.1	27.4															
6	54.7	88.4	0.0	0.1	24.3	54.7	61.1	19.0	0.1	27.4	54.7	61.1	23.5	0.16	24.4										
8	54.7	143.6	0.0	0.2	16.3	54.7	79.3	19.0	0.1	26.4	54.7	61.1	23.5	0.16	24.4	54.7	61.1	28.1	0.20	25.6					
10	54.7	199.3	0.0	0.2	12.3	54.7	122.1	19.0	0.2	18.7	54.7	61.1	23.5	0.16	30.5	54.7	61.1	28.1	0.20	25.6	54.7	61.1	32.6	0.23	24.1
12	54.7	255.2	0.0	0.3	9.8	54.7	170.2	19.0	0.2	14.1	54.7	88.2	23.5	0.18	24.3	54.7	61.1	28.1	0.20	30.7	54.7	61.1	32.6	0.23	24.1
14						54.7	221.2	19.0	0.3	11.2	54.7	130.4	23.5	0.22	17.7	54.7	81.4	28.1	0.21	25.9	54.7	61.1	32.6	0.23	28.1
16						54.7	273.9	19.0	0.3	9.2	54.7	177.8	23.5	0.26	13.6	54.7	114.5	28.1	0.24	19.7	54.7	62.0	32.6	0.23	31.6
18											54.7	228.3	23.5	0.31	10.9	54.7	154.2	28.1	0.28	15.4	54.7	88.1	32.6	0.25	24.3
20											54.7	280.5	23.5	0.35	9.0	54.7	198.9	28.1	0.32	12.3	54.7	121.5	32.6	0.28	18.8
22																54.7	247.0	28.1	0.36	10.1	54.7	161.2	32.6	0.32	14.8
24																54.7	297.2	28.1	0.40	8.6	54.7	205.6	32.6	0.36	12.0
26																					54.7	253.4	32.6	0.40	9.9
28																					54.7	303.4	32.6	0.44	8.4

Length B vs Deflection 3000 psi 1/4" OD
(20.7 MPa, 6 mm OD)



Weight vs. Deflection 3000 psi 1/4" OD
(20.7 MPa, 6 mm OD)



Force vs. Deflection 3000 psi 1/4" OD
(20.7 MPa, 6 mm OD)

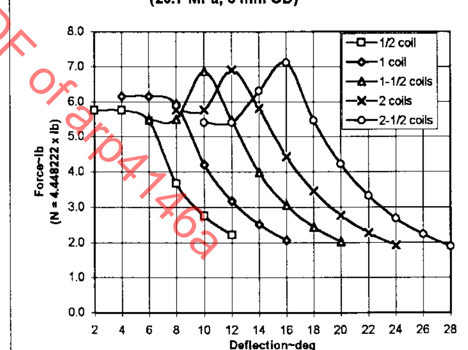


FIGURE A2 - Design Data for 3000 psi Style A

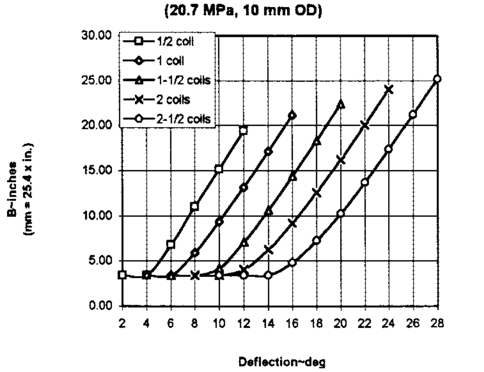
ϕ3/8" x .025 3000 psi Rc = 2.63/2.72 in. PITCH = 0.49±0.04 in. D = 5.26/5.39 in.

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2	3.05	3.42	0.00	0.048	10.3																				
4	3.05	3.42	0.00	0.048	10.3	3.05	3.42	1.13	0.067	10.7															
6	3.05	6.86	0.00	0.079	6.4	3.05	3.42	1.13	0.067	10.7	3.05	3.42	1.39	0.085	9.5										
8	3.05	11.01	0.00	0.115	4.2	3.05	5.93	1.13	0.089	7.2	3.05	3.42	1.39	0.085	9.5	3.047	3.42	1.66	0.10	9.8					
10	3.05	15.20	0.00	0.152	3.2	3.05	9.38	1.13	0.119	4.9	3.05	4.20	1.39	0.092	9.5	3.05	3.42	1.66	0.103	9.8	3.05	3.42	1.92	0.121	9.2
12	3.05	19.41	0.00	0.189	2.5	3.05	13.18	1.13	0.152	3.6	3.05	7.11	1.39	0.117	6.2	3.047	4.08	1.66	0.11	9.7	3.047	3.42	1.9178	0.121	9.2
14						3.05	17.14	1.13	0.187	2.8	3.05	10.60	1.39	0.148	4.4	3.05	6.31	1.66	0.128	6.9	3.05	3.42	1.92	0.121	10.8
16						3.05	21.20	1.13	0.223	2.3	3.05	14.40	1.39	0.181	3.3	3.047	9.20	1.66	0.15	5.0	3.047	4.87	1.9178	0.134	8.5
18											3.05	18.36	1.39	0.216	2.7	3.047	12.58	1.66	0.18	3.8	3.047	7.27	1.9178	0.155	6.1
20											3.05	22.40	1.39	0.252	2.2	3.047	16.25	1.66	0.22	3.0	3.047	10.27	1.9178	0.181	4.5
22																3.047	20.10	1.66	0.25	2.4	3.047	13.70	1.9178	0.212	3.5
24																3.047	24.06	1.66	0.28	2.1	3.047	17.40	1.9178	0.244	2.8
26																					3.047	21.26	1.9178	0.278	2.3
28																					3.05	25.22	1.92	0.313	1.97

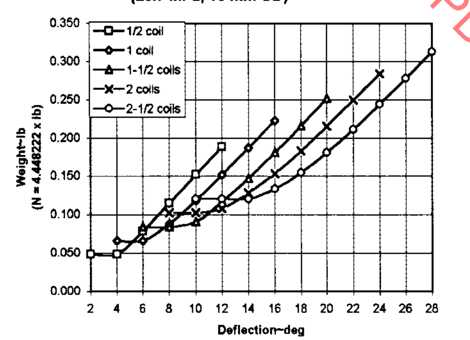
ϕ10 mm x 0.64 mm 20.7 MPa Rc = 66.8/69.1 mm PITCH =12.4±1.0 mm D = 133.6/136.9 mm

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2	77.4	86.9	0.0	0.2	45.7																				
4	77.4	86.9	0.0	0.2	45.7	77.4	86.9	28.7	0.3	47.6															
6	77.4	174.1	0.0	0.3	28.5	77.4	86.9	28.7	0.3	47.6	77.4	86.9	35.4	0.38	42.2										
8	77.4	279.7	0.0	0.5	18.9	77.4	150.7	28.7	0.4	32.1	77.4	86.9	35.4	0.38	42.2	77.4	86.9	42.1	0.46	43.8					
10	77.4	386.2	0.0	0.7	14.1	77.4	238.2	28.7	0.5	21.8	77.4	106.7	35.4	0.41	42.2	77.4	86.9	42.1	0.46	43.8	77.4	86.9	48.7	0.54	41.1
12	77.4	493.0	0.0	0.8	11.2	77.4	334.7	28.7	0.7	16.1	77.4	180.5	35.4	0.52	27.7	77.4	103.7	42.1	0.48	43.2	77.4	86.9	48.7	0.54	41.1
14						77.4	435.4	28.7	0.8	12.6	77.4	269.2	35.4	0.66	19.6	77.4	160.3	42.1	0.57	30.6	77.4	86.9	48.7	0.54	47.9
16						77.4	538.5	28.7	1.0	10.3	77.4	365.7	35.4	0.81	14.8	77.4	233.8	42.1	0.68	22.2	77.4	123.7	48.7	0.60	37.7
18											77.4	466.2	35.4	0.96	11.8	77.4	319.5	42.1	0.82	16.8	77.4	184.6	48.7	0.69	27.1
20											77.4	569.0	35.4	1.12	9.8	77.4	412.8	42.1	0.96	13.3	77.4	261.0	48.7	0.81	20.1
22																77.4	510.6	42.1	1.11	10.9	77.4	348.1	48.7	0.94	15.5
24																77.4	611.1	42.1	1.27	9.2	77.4	442.0	48.7	1.09	12.4
26																					77.4	540.0	48.7	1.24	10.3
28																					77.4	640.6	48.7	1.39	8.8

Length B vs. Deflection 3000 psi 3/8" OD
(20.7 MPa, 10 mm OD)



Weight vs. Deflection 3000 psi 3/8" OD
(20.7 MPa, 10 mm OD)



Force vs. Deflection 3000 psi 3/8" OD
(20.7 MPa, 10 mm OD)

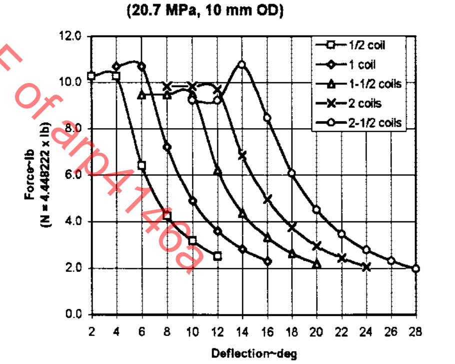
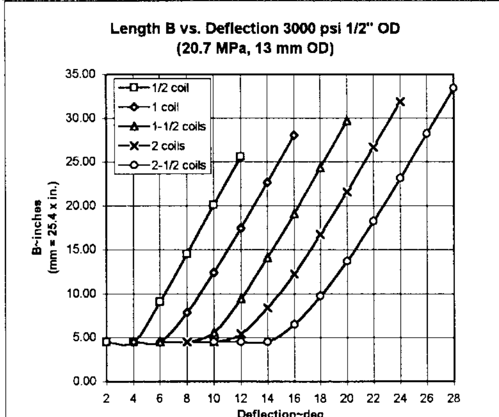
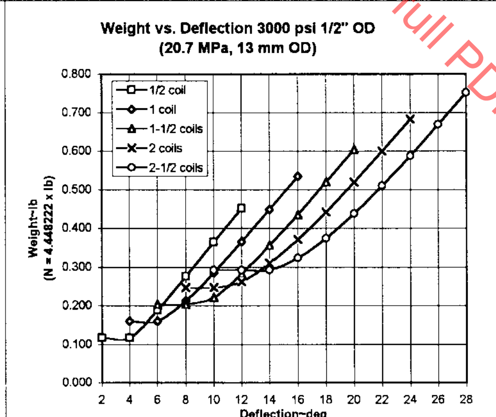


FIGURE A2 (Continued)

	ϕ1/2" x .034 3000 psi					Rc = 3.50/3.62 in.					Pitch = 0.63±0.06 in.					D = 7.00/7.27 in.									
	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2	4.06	4.56	0.00	0.117	18.8																				
4	4.06	4.56	0.00	0.117	18.8	4.06	4.56	1.49	0.161	19.6															
6	4.06	9.09	0.00	0.189	11.8	4.06	4.56	1.49	0.161	19.6	4.06	4.56	1.83	0.204	17.4										
8	4.06	14.56	0.00	0.276	7.8	4.06	7.90	1.49	0.214	13.2	4.06	4.56	1.83	0.204	17.4	4.0594	4.56	2.18	0.25	18.0					
10	4.06	20.09	0.00	0.364	5.8	4.06	12.45	1.49	0.286	9.0	4.06	5.62	1.83	0.221	17.3	4.06	4.56	2.18	0.248	18.0	4.06	4.56	2.52	0.292	16.9
12	4.06	25.63	0.00	0.452	4.7	4.06	17.46	1.49	0.366	6.6	4.06	9.48	1.83	0.283	11.4	4.0594	5.47	2.18	0.26	17.7	4.0594	4.56	2.522	0.292	16.9
14						4.06	22.69	1.49	0.449	5.2	4.06	14.09	1.83	0.356	8.1	4.06	8.44	2.18	0.310	12.5	4.06	4.56	2.52	0.292	19.8
16						4.06	28.03	1.49	0.534	4.3	4.06	19.11	1.83	0.436	6.1	4.0594	12.28	2.18	0.37	9.1	4.0594	6.54	2.522	0.323	15.4
18											4.06	24.32	1.83	0.519	4.9	4.0594	16.74	2.18	0.44	6.9	4.0594	9.74	2.522	0.374	11.1
20											4.06	29.66	1.83	0.604	4.1	4.0594	21.58	2.18	0.52	5.5	4.0594	13.72	2.522	0.438	8.2
22																4.0594	26.66	2.18	0.60	4.5	4.0594	18.26	2.522	0.510	6.4
24																4.0594	31.88	2.18	0.68	3.8	4.0594	23.14	2.522	0.588	5.1
26																					4.0594	28.23	2.522	0.669	4.3
28																					4.0594	33.45	2.522	0.752	3.6

	ϕ13 mm x 0.86 mm 20.7 MPa					Rc =88.9/92.0 mm					PITCH =16.0±1.5 mm					D = 177.8/184.7 mm									
	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2	103.1	115.8	0.0	0.5	83.7																				
4	103.1	115.8	0.0	0.5	83.7	103.1	115.8	37.8	0.7	87.1															
6	103.1	230.8	0.0	0.8	52.4	103.1	115.8	37.8	0.7	87.1	103.1	115.8	46.6	0.91	77.3										
8	103.1	369.9	0.0	1.2	34.8	103.1	200.6	37.8	1.0	58.8	103.1	115.8	46.6	0.91	77.3	103.1	115.8	55.3	1.10	80.3					
10	103.1	510.3	0.0	1.6	26.0	103.1	316.2	37.8	1.3	40.0	103.1	142.9	46.6	0.98	77.0	103.1	115.8	55.3	1.10	80.3	103.1	115.8	64.1	1.30	75.4
12	103.1	651.1	0.0	2.0	20.7	103.1	443.4	37.8	1.6	29.6	103.1	240.7	46.6	1.26	50.6	103.1	139.0	55.3	1.17	78.6	103.1	115.8	64.1	1.30	75.4
14						103.1	576.2	37.8	2.0	23.2	103.1	358.0	46.6	1.58	35.8	103.1	214.3	55.3	1.38	55.7	103.1	115.8	64.1	1.30	87.9
16						103.1	712.0	37.8	2.4	19.1	103.1	485.3	46.6	1.94	27.2	103.1	311.8	55.3	1.65	40.5	103.1	166.1	64.1	1.44	68.5
18											103.1	617.8	46.6	2.31	21.8	103.1	425.1	55.3	1.97	30.7	103.1	247.3	64.1	1.67	49.4
20											103.1	753.3	46.6	2.69	18.1	103.1	548.2	55.3	2.31	24.3	103.1	348.6	64.1	1.95	36.7
22																103.1	677.2	55.3	2.67	20.0	103.1	463.8	64.1	2.27	28.4
24																103.1	809.8	55.3	3.04	16.9	103.1	587.7	64.1	2.61	22.8
26																					103.1	717.0	64.1	2.98	18.9
28																					103.1	849.7	64.1	3.35	16.1





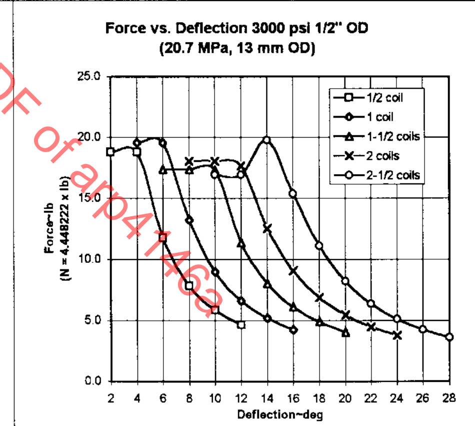


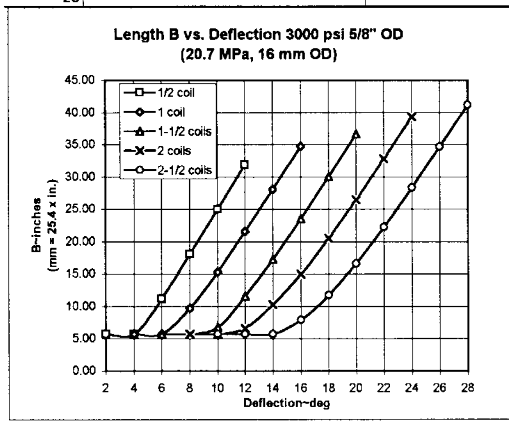
FIGURE A2 (Continued)

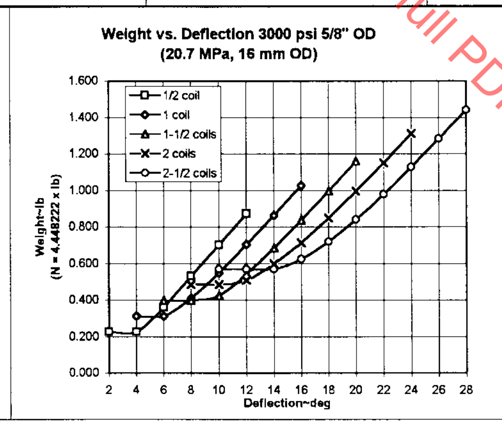
ϕ5/8" x .042 3000 psi Rc = 4.44/4.63 in. Pitch = 0.80±0.07 in. D = 8.88/9.27 in.

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2	5.11	5.73	0.00	0.228	28.6																				
4	5.11	5.73	0.00	0.228	28.6	5.11	5.73	1.84	0.313	29.8															
6	5.11	11.24	0.00	0.363	18.4	5.11	5.73	1.84	0.313	29.8	5.11	5.73	2.26	0.399	26.4										
8	5.11	18.08	0.00	0.531	12.2	5.11	9.73	1.84	0.412	20.7	5.11	5.73	2.26	0.399	26.4	5.1067	5.73	2.69	0.49	27.5					
10	5.11	24.98	0.00	0.701	9.1	5.11	15.37	1.84	0.551	14.0	5.11	6.86	2.26	0.427	27.2	5.11	5.73	2.69	0.485	27.5	5.11	5.73	3.12	0.571	25.8
12	5.11	31.90	0.00	0.872	7.2	5.11	21.60	1.84	0.704	10.4	5.11	11.59	2.26	0.543	17.9	5.1067	6.70	2.69	0.51	27.7	5.1067	5.73	3.1173	0.571	25.8
14						5.11	28.12	1.84	0.864	8.1	5.11	17.29	2.26	0.684	12.7	5.11	10.30	2.69	0.598	19.7	5.11	5.73	3.12	0.571	30.1
16						5.11	34.79	1.84	1.029	6.7	5.11	23.52	2.26	0.837	9.6	5.1067	15.01	2.69	0.71	14.3	5.1067	7.94	3.1173	0.625	24.3
18											5.11	30.02	2.26	0.997	7.7	5.1067	20.51	2.69	0.85	10.9	5.1067	11.81	3.1173	0.721	17.6
20											5.11	36.67	2.26	1.161	6.4	5.1067	26.52	2.69	1.00	8.6	5.1067	16.69	3.1173	0.841	13.1
22																5.1067	32.83	2.69	1.15	7.0	5.1067	22.28	3.1173	0.978	10.1
24																5.1067	39.33	2.69	1.31	5.9	5.1067	28.32	3.1173	1.127	8.1
26																					5.1067	34.65	3.1173	1.283	6.7
28																					5.1067	41.15	3.1173	1.443	5.7

ϕ16 mm x 1.07 mm 20.7 MPa Rc =112.8/117.6 mm PITCH =20.3±1.8 mm D = 225.6/235.5 mm

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2	129.7	145.6	0.0	1.0	127.3																				
4	129.7	145.6	0.0	1.0	127.3	129.7	145.6	46.6	1.4	132.6															
6	129.7	285.5	0.0	1.6	81.6	129.7	145.6	46.6	1.4	132.6	129.7	145.6	57.5	1.78	117.5										
8	129.7	459.2	0.0	2.4	54.1	129.7	247.3	46.6	1.8	91.9	129.7	145.6	57.5	1.78	117.5	129.7	145.6	68.3	2.16	122.1					
10	129.7	634.5	0.0	3.1	40.4	129.7	390.5	46.6	2.4	62.5	129.7	174.2	57.5	1.90	121.0	129.7	145.6	68.3	2.16	122.1	129.7	145.6	79.2	2.54	114.6
12	129.7	810.4	0.0	3.9	32.2	129.7	548.7	46.6	3.1	46.1	129.7	294.3	57.5	2.42	79.6	129.7	170.1	68.3	2.26	123.3	129.7	145.6	79.2	2.54	114.6
14						129.7	714.2	46.6	3.8	36.2	129.7	439.3	57.5	3.04	56.3	129.7	261.7	68.3	2.66	87.8	129.7	145.6	79.2	2.54	133.7
16						129.7	883.6	46.6	4.6	29.7	129.7	597.4	57.5	3.72	42.7	129.7	381.2	68.3	3.17	63.8	129.7	201.6	79.2	2.78	108.2
18											129.7	762.5	57.5	4.44	34.1	129.7	521.0	68.3	3.78	48.4	129.7	300.0	79.2	3.21	78.3
20											129.7	931.3	57.5	5.16	28.3	129.7	673.6	68.3	4.43	38.2	129.7	423.8	79.2	3.74	58.1
22																129.7	833.9	68.3	5.12	31.4	129.7	565.8	79.2	4.35	44.9
24																129.7	999.0	68.3	5.84	26.5	129.7	719.4	79.2	5.01	36.0
26																					129.7	880.0	79.2	5.71	29.8
28																					129.7	1045.1	79.2	6.42	25.3





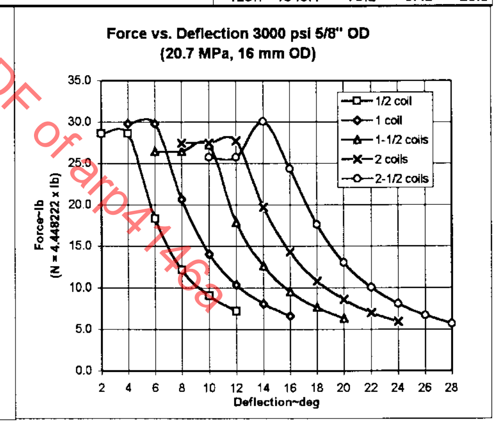
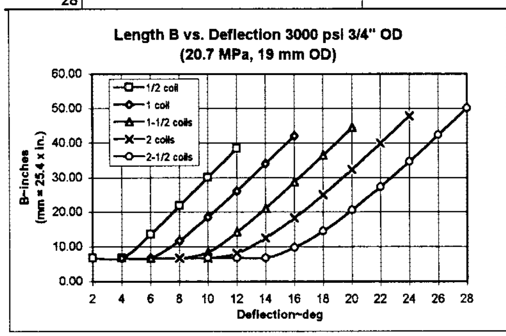
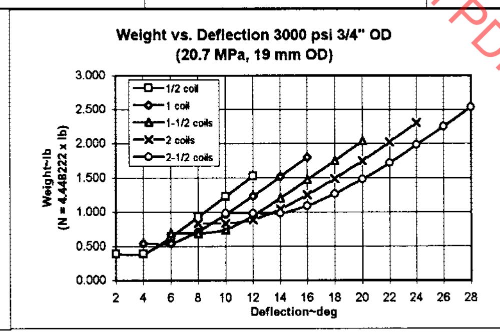


FIGURE A2 (Continued)

	ϕ3/4" x .051 3000 psi					Rc = 5.25/5.50 in.					Pitch = 0.94±0.09 in.					D =10.50/11.01 in.									
	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2	6.09	6.84	0.00	0.394	42.3																				
4	6.09	6.84	0.00	0.394	42.3	6.09	6.84	2.20	0.542	44.1															
6	6.09	13.63	0.00	0.637	26.5	6.09	6.84	2.20	0.542	44.1	6.09	6.84	2.71	0.689	39.1										
8	6.09	21.85	0.00	0.932	17.6	6.09	11.85	2.20	0.721	29.8	6.09	6.84	2.71	0.689	39.1	6.0891	6.84	3.22	0.84	40.6					
10	6.09	30.13	0.00	1.229	13.2	6.09	18.67	2.20	0.966	20.2	6.09	8.44	2.71	0.747	38.9	6.09	6.84	3.22	0.837	40.6	6.09	6.84	3.73	0.985	38.1
12	6.09	38.45	0.00	1.527	10.5	6.09	26.19	2.20	1.235	15.0	6.09	14.22	2.71	0.954	25.6	6.0891	8.21	3.22	0.89	39.8	6.0891	6.84	3.7291	0.985	38.1
14						6.09	34.03	2.20	1.516	11.8	6.09	21.14	2.71	1.202	18.1	6.09	12.66	3.22	1.046	28.2	6.09	6.84	3.73	0.985	44.5
16						6.09	42.05	2.20	1.804	9.6	6.09	28.66	2.71	1.471	13.8	6.0891	18.41	3.22	1.25	20.5	6.0891	9.81	3.7291	1.091	34.6
18											6.09	36.49	2.71	1.752	11.0	6.0891	25.11	3.22	1.49	15.5	6.0891	14.61	3.7291	1.263	25.0
20											6.09	44.48	2.71	2.039	9.1	6.0891	32.38	3.22	1.75	12.3	6.0891	20.58	3.7291	1.478	18.6
22																6.0891	39.99	3.22	2.03	10.1	6.0891	27.39	3.7291	1.721	14.4
24																6.0891	47.82	3.22	2.31	8.5	6.0891	34.71	3.7291	1.984	11.5
26																					6.0891	42.34	3.7291	2.257	9.6
28																					6.0891	50.18	3.7291	2.538	8.2

	ϕ19 mm x 1.30 mm 20.7 MPa					Rc =133.4/139.7 mm					PITCH =23.9±2.3 mm					D = 266.7/279.7 mm									
	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2	154.7	173.7	0.0	1.8	188.3																				
4	154.7	173.7	0.0	1.8	188.3	154.7	173.7	55.9	2.4	196.1															
6	154.7	346.2	0.0	2.8	117.9	154.7	173.7	55.9	2.4	196.1	154.7	173.7	68.8	3.07	173.9										
8	154.7	554.9	0.0	4.1	78.3	154.7	300.9	55.9	3.2	132.4	154.7	173.7	68.8	3.07	173.9	154.7	173.7	81.8	3.72	180.6					
10	154.7	765.4	0.0	5.5	58.5	154.7	474.3	55.9	4.3	90.0	154.7	214.3	68.8	3.32	173.2	154.7	173.7	81.8	3.72	180.6	154.7	173.7	94.7	4.38	169.6
12	154.7	976.6	0.0	6.8	46.7	154.7	665.1	55.9	5.5	66.5	154.7	361.1	68.8	4.24	113.8	154.7	208.4	81.8	3.94	176.9	154.7	173.7	94.7	4.38	169.6
14						154.7	864.4	55.9	6.7	52.3	154.7	536.9	68.8	5.35	80.6	154.7	321.5	81.8	4.65	125.4	154.7	173.7	94.7	4.38	197.8
16						154.7	1068.0	55.9	8.0	42.9	154.7	727.9	68.8	6.55	61.3	154.7	467.7	81.8	5.57	91.1	154.7	249.2	94.7	4.86	154.1
18											154.7	926.7	68.8	7.79	49.0	154.7	637.7	81.8	6.64	69.1	154.7	371.0	94.7	5.62	111.2
20											154.7	1129.9	68.8	9.07	40.7	154.7	822.3	81.8	7.80	54.7	154.7	522.8	94.7	6.57	82.6
22																154.7	1015.8	81.8	9.01	45.0	154.7	695.7	94.7	7.66	63.8
24																154.7	1214.7	81.8	10.26	38.0	154.7	881.6	94.7	8.82	51.3
26																					154.7	1075.5	94.7	10.04	42.6
28																					154.7	1274.5	94.7	11.29	36.3





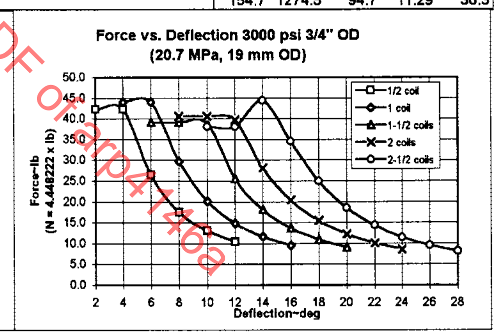


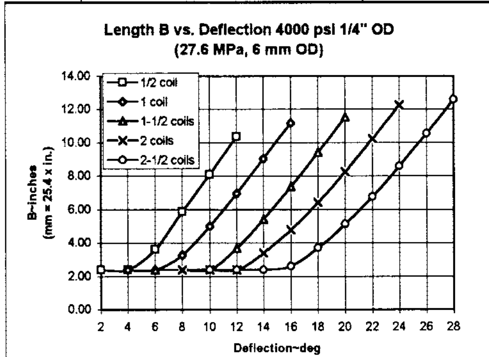
FIGURE A2 (Continued)

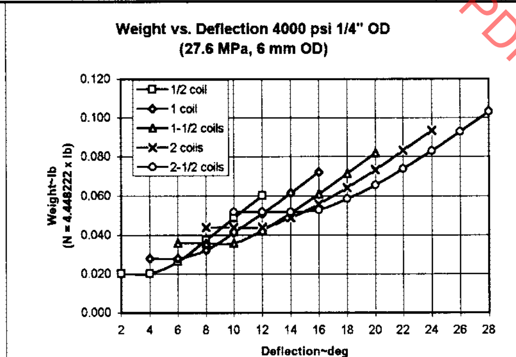
ϕ1/4" x .022 4000 psi   Rc = 2.00/2.09 in.   Pitch = 0.33±0.03 in.   D = 4.00/4.19 in.

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2	2.15	2.40	0.00	0.020	5.8																				
4	2.15	2.40	0.00	0.020	5.8	2.15	2.40	0.75	0.028	6.2															
6	2.15	3.64	0.00	0.026	5.2	2.15	2.40	0.75	0.028	6.2	2.15	2.40	0.93	0.036	5.5										
8	2.15	5.86	0.00	0.038	3.5	2.15	3.27	0.75	0.032	5.6	2.15	2.40	0.93	0.036	5.5	2.1547	2.40	1.11	0.04	5.8					
10	2.15	8.11	0.00	0.049	2.6	2.15	5.02	0.75	0.041	4.0	2.15	2.40	0.93	0.036	6.9	2.15	2.40	1.11	0.044	5.8	2.15	2.40	1.29	0.052	5.4
12	2.15	10.36	0.00	0.060	2.1	2.15	6.98	0.75	0.051	3.0	2.15	3.69	0.93	0.042	5.1	2.1547	2.40	1.11	0.04	6.9	2.1547	2.40	1.2853	0.052	5.4
14						2.15	9.05	0.75	0.062	2.4	2.15	5.43	0.93	0.051	3.7	2.15	3.40	1.11	0.049	5.4	2.15	2.40	1.29	0.052	6.3
16						2.15	11.19	0.75	0.072	2.0	2.15	7.37	0.93	0.061	2.9	2.1547	4.79	1.11	0.06	4.1	2.1547	2.61	1.2853	0.053	6.6
18											2.15	9.42	0.93	0.071	2.3	2.1547	6.44	1.11	0.06	3.2	2.1547	3.73	1.2853	0.058	5.1
20											2.15	11.54	0.93	0.082	1.9	2.1547	8.27	1.11	0.07	2.6	2.1547	5.13	1.2853	0.066	3.9
22																2.1547	10.24	1.11	0.08	2.1	2.1547	6.79	1.2853	0.074	3.1
24																2.1547	12.28	1.11	0.09	1.8	2.1547	8.62	1.2853	0.083	2.5
26																					2.1547	10.58	1.2853	0.093	2.1
28																					2.1547	12.62	1.2853	0.103	1.8

ϕ6 mm x 0.6mm 27.6 MPa   Rc = 50.8/53.1 mm   PITCH =8.4±0.8 mm   D = 101.6/106.4 mm

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2	54.7	61.1	0.0	0.1	25.6																				
4	54.7	61.1	0.0	0.1	25.6	54.7	61.1	19.0	0.1	27.4															
6	54.7	92.4	0.0	0.1	22.9	54.7	61.1	19.0	0.1	27.4	54.7	61.1	23.5	0.16	24.4										
8	54.7	148.9	0.0	0.2	15.5	54.7	83.1	19.0	0.1	24.9	54.7	61.1	23.5	0.16	24.4	54.7	61.1	28.1	0.20	25.6					
10	54.7	206.0	0.0	0.2	11.7	54.7	127.6	19.0	0.2	17.6	54.7	61.1	23.5	0.16	30.5	54.7	61.1	28.1	0.20	25.6	54.7	61.1	32.6	0.23	24.1
12	54.7	263.3	0.0	0.3	9.3	54.7	177.3	19.0	0.2	13.3	54.7	93.8	23.5	0.19	22.6	54.7	61.1	28.1	0.20	30.7	54.7	61.1	32.6	0.23	24.1
14						54.7	229.9	19.0	0.3	10.6	54.7	138.0	23.5	0.23	16.5	54.7	86.4	28.1	0.22	24.1	54.7	61.1	32.6	0.23	28.1
16						54.7	284.1	19.0	0.3	8.7	54.7	187.3	23.5	0.27	12.7	54.7	121.6	28.1	0.25	18.4	54.7	66.4	32.6	0.23	29.4
18											54.7	239.4	23.5	0.32	10.2	54.7	163.5	28.1	0.29	14.3	54.7	94.7	32.6	0.26	22.5
20											54.7	293.2	23.5	0.36	8.5	54.7	210.1	28.1	0.33	11.5	54.7	130.4	32.6	0.29	17.3
22																54.7	260.0	28.1	0.37	9.5	54.7	172.4	32.6	0.33	13.6
24																54.7	311.9	28.1	0.42	8.0	54.7	219.0	32.6	0.37	11.0
26																					54.7	268.7	32.6	0.41	9.2
28																					54.7	320.4	32.6	0.46	7.8





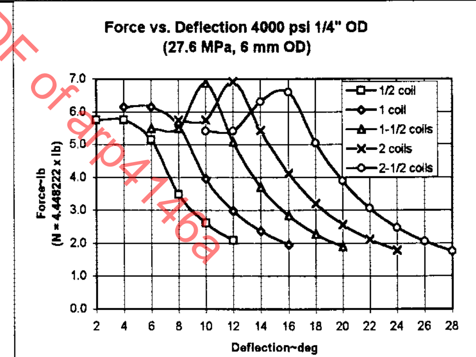
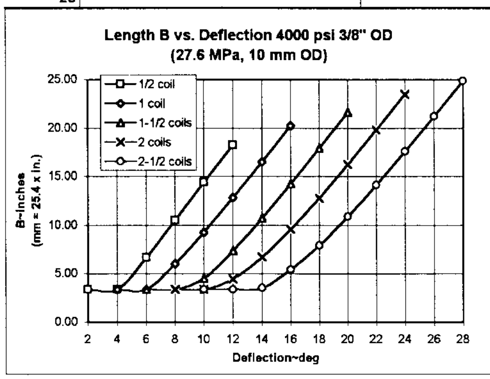


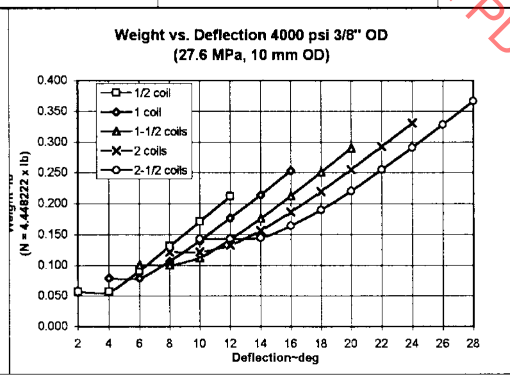
FIGURE A3 - Design Data for 4000 psi Style A ϕ3/8" x .030 4000 psi — Rc = 2.63/2.72 in. — PITCH = 0.49±0.04 in. — D = 5.26/5.39 in.

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2	3.05	3.42	0.00	0.057	13.0																				
4	3.05	3.42	0.00	0.057	13.0	3.05	3.42	1.13	0.079	13.7															
6	3.05	6.71	0.00	0.091	8.2	3.05	3.42	1.13	0.079	13.7	3.05	3.42	1.39	0.100	12.3										
8	3.05	10.54	0.00	0.131	5.5	3.05	6.05	1.13	0.106	8.9	3.05	3.42	1.39	0.100	12.3	3.047	3.42	1.66	0.12	12.8					
10	3.05	14.40	0.00	0.171	4.2	3.05	9.31	1.13	0.140	6.2	3.05	4.55	1.39	0.112	11.2	3.05	3.42	1.66	0.122	12.8	3.05	3.42	1.92	0.143	12.0
12	3.05	18.27	0.00	0.212	3.4	3.05	12.84	1.13	0.177	4.6	3.05	7.42	1.39	0.142	7.5	3.047	4.45	1.66	0.13	11.4	3.047	3.42	1.9178	0.143	12.0
14						3.05	16.50	1.13	0.215	3.7	3.05	10.73	1.39	0.176	5.5	3.05	6.75	1.66	0.156	8.1	3.05	3.56	1.92	0.145	13.5
16						3.05	20.24	1.13	0.254	3.0	3.05	14.27	1.39	0.213	4.2	3.047	9.60	1.66	0.19	6.0	3.047	5.44	1.9178	0.164	9.7
18											3.05	17.94	1.39	0.251	3.4	3.047	12.82	1.66	0.22	4.6	3.047	7.92	1.9178	0.190	7.1
20											3.05	21.67	1.39	0.290	2.9	3.047	16.26	1.66	0.26	3.7	3.047	10.88	1.9178	0.221	5.4
22																3.047	19.84	1.66	0.29	3.1	3.047	14.16	1.9178	0.255	4.2
24																3.047	23.50	1.66	0.33	2.6	3.047	17.63	1.9178	0.291	3.5
26																					3.047	21.22	1.9178	0.328	2.9
28																					3.047	24.89	1.9178	0.367	2.5

ϕ10 mm x 0.76 mm 34.5 MPa — Rc = 66.8/69.1 mm — PITCH =12.4±1.0 mm — D = 133.6/136.9 mm

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2	77.4	86.9	0.0	0.3	58.0																				
4	77.4	86.9	0.0	0.3	58.0	77.4	86.9	28.7	0.4	61.1															
6	77.4	170.3	0.0	0.4	36.4	77.4	86.9	28.7	0.4	61.1	77.4	86.9	35.4	0.45	54.6										
8	77.4	267.7	0.0	0.6	24.6	77.4	153.7	28.7	0.5	39.6	77.4	86.9	35.4	0.45	54.6	77.4	86.9	42.1	0.54	56.8					
10	77.4	365.7	0.0	0.8	18.6	77.4	236.4	28.7	0.6	27.5	77.4	115.6	35.4	0.50	49.8	77.4	86.9	42.1	0.54	56.8	77.4	86.9	48.7	0.64	53.5
12	77.4	464.1	0.0	0.9	14.9	77.4	326.1	28.7	0.8	20.6	77.4	188.4	35.4	0.63	33.4	77.4	113.1	42.1	0.59	50.6	77.4	86.9	48.7	0.64	53.5
14						77.4	419.2	28.7	1.0	16.4	77.4	272.5	35.4	0.78	24.2	77.4	171.6	42.1	0.70	36.2	77.4	90.4	48.7	0.64	59.9
16						77.4	514.2	28.7	1.1	13.5	77.4	362.5	35.4	0.95	18.7	77.4	243.9	42.1	0.83	26.7	77.4	138.1	48.7	0.73	43.3
18											77.4	455.6	35.4	1.12	15.2	77.4	325.6	42.1	0.98	20.7	77.4	201.2	48.7	0.85	31.6
20											77.4	550.4	35.4	1.29	12.7	77.4	413.1	42.1	1.14	16.6	77.4	276.4	48.7	0.98	23.9
22																77.4	504.0	42.1	1.30	13.8	77.4	359.6	48.7	1.13	18.9
24																77.4	597.0	42.1	1.47	11.8	77.4	447.8	48.7	1.29	15.4
26																					77.4	539.0	48.7	1.46	13.0
28																					77.4	632.2	48.7	1.63	11.1





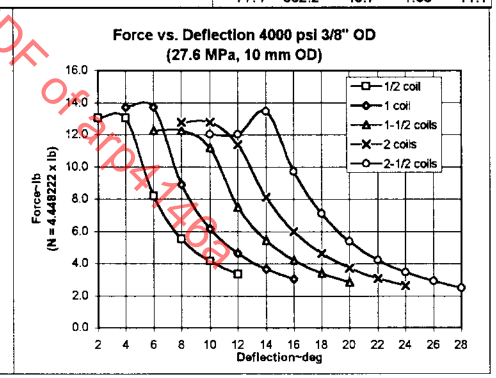


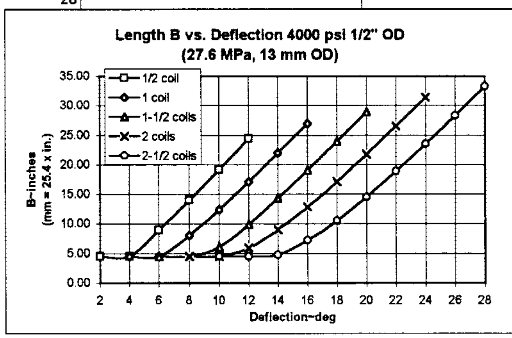
FIGURE A3 (Continued)

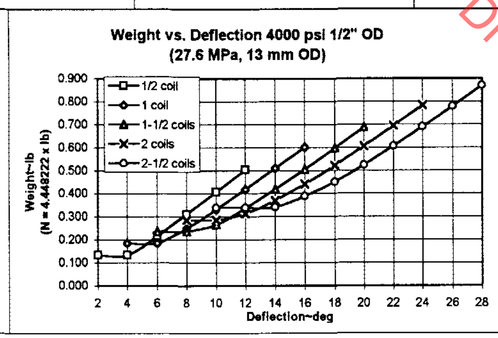
ϕ1/2" x .040 4000 psi — Rc = 3.50/3.62 in. — Pitch = 0.63±0.06 in. — D = 7.00/7.27 in.

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2	4.06	4.56	0.00	0.136	23.2																				
4	4.06	4.56	0.00	0.136	23.2	4.06	4.56	1.49	0.186	24.4															
6	4.06	8.96	0.00	0.217	14.5	4.06	4.56	1.49	0.186	24.4	4.06	4.56	1.83	0.237	21.8										
8	4.06	14.08	0.00	0.312	9.8	4.06	8.09	1.49	0.252	15.8	4.06	4.56	1.83	0.237	21.8	4.0594	4.56	2.18	0.29	22.8					
10	4.06	19.23	0.00	0.407	7.4	4.06	12.44	1.49	0.332	11.0	4.06	6.09	1.83	0.266	19.8	4.06	4.56	2.18	0.288	22.8	4.06	4.56	2.52	0.339	21.4
12	4.06	24.40	0.00	0.502	5.9	4.06	17.15	1.49	0.419	8.2	4.06	9.92	1.83	0.336	13.3	4.0594	5.96	2.18	0.31	20.2	4.0594	4.56	2.522	0.339	21.4
14						4.06	22.05	1.49	0.510	6.5	4.06	14.35	1.83	0.418	9.7	4.06	9.04	2.18	0.371	14.4	4.06	4.76	2.52	0.343	23.9
16						4.06	27.04	1.49	0.602	5.4	4.06	19.08	1.83	0.506	7.5	4.0594	12.85	2.18	0.44	10.6	4.0594	7.28	2.522	0.389	17.2
18											4.06	23.97	1.83	0.596	6.0	4.0594	17.15	2.18	0.52	8.2	4.0594	10.60	2.522	0.451	12.6
20											4.06	28.96	1.83	0.689	5.1	4.0594	21.74	2.18	0.61	6.6	4.0594	14.57	2.522	0.524	9.5
22																4.0594	26.52	2.18	0.69	5.5	4.0594	18.95	2.522	0.605	7.5
24																4.0594	31.42	2.18	0.78	4.7	4.0594	23.58	2.522	0.691	6.1
26																					4.0594	28.38	2.522	0.780	5.2
28																					4.0594	33.28	2.522	0.870	4.4

ϕ13 mm x 1.0mm 34.5 MPa — Rc =89.0/92.0 mm — PITCH =16.0±1.5 mm — D = 177.8/184.6 mm

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2	103.1	115.8	0.0	0.6	103.3																				
4	103.1	115.8	0.0	0.6	103.3	103.1	115.8	37.8	0.8	108.7															
6	103.1	227.6	0.0	1.0	64.6	103.1	115.8	37.8	0.8	108.7	103.1	115.8	46.6	1.06	97.2										
8	103.1	357.6	0.0	1.4	43.7	103.1	205.4	37.8	1.1	70.3	103.1	115.8	46.6	1.06	97.2	103.1	115.8	55.3	1.28	101.2					
10	103.1	488.4	0.0	1.8	33.0	103.1	315.9	37.8	1.5	48.7	103.1	154.7	46.6	1.18	88.2	103.1	115.8	55.3	1.28	101.2	103.1	115.8	64.1	1.51	95.3
12	103.1	619.6	0.0	2.2	26.4	103.1	435.6	37.8	1.9	36.6	103.1	252.0	46.6	1.50	59.2	103.1	151.3	55.3	1.40	89.7	103.1	115.8	64.1	1.51	95.3
14						103.1	560.0	37.8	2.3	29.1	103.1	364.4	46.6	1.86	43.0	103.1	229.5	55.3	1.65	64.1	103.1	121.0	64.1	1.52	106.2
16						103.1	686.8	37.8	2.7	24.0	103.1	484.6	46.6	2.25	33.2	103.1	326.3	55.3	1.96	47.4	103.1	184.9	64.1	1.73	76.6
18											103.1	608.9	46.6	2.65	26.9	103.1	435.5	55.3	2.32	36.6	103.1	269.4	64.1	2.01	56.0
20											103.1	735.5	46.6	3.06	22.5	103.1	552.3	55.3	2.70	29.4	103.1	370.0	64.1	2.33	42.4
22																103.1	673.7	55.3	3.09	24.5	103.1	481.2	64.1	2.69	33.4
24																103.1	798.0	55.3	3.49	20.8	103.1	599.0	64.1	3.07	27.3
26																					103.1	720.8	64.1	3.47	23.0
28																					103.1	845.3	64.1	3.87	19.7





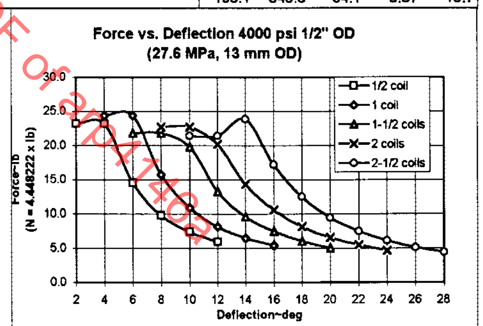


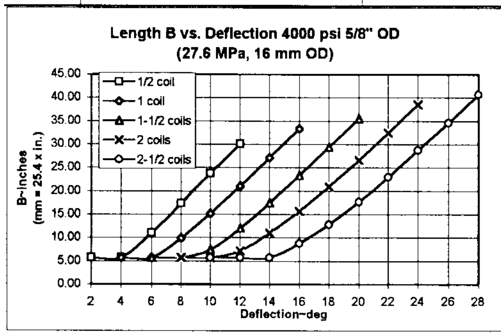
FIGURE A3 (Continued)

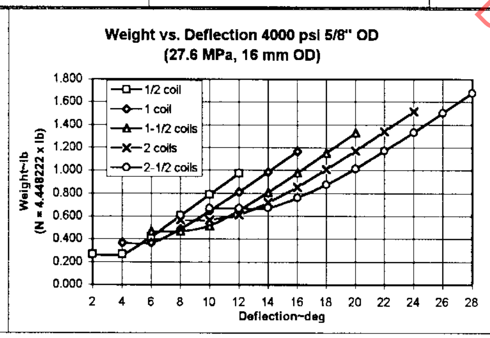
ϕ5/8" x .050 4000 psi   Rc = 4.44/4.63 in.   Pitch = 0.80±0.07 in.   D = 8.88/9.27 in.

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2	5.11	5.73	0.00	0.267	35.9																				
4	5.11	5.73	0.00	0.267	35.9	5.11	5.73	1.84	0.368	37.8															
6	5.11	11.02	0.00	0.420	23.1	5.11	5.73	1.84	0.368	37.8	5.11	5.73	2.26	0.469	33.7										
8	5.11	17.36	0.00	0.603	15.6	5.11	9.93	1.84	0.489	25.2	5.11	5.73	2.26	0.469	33.7	5.1067	5.73	2.69	0.57	35.2					
10	5.11	23.75	0.00	0.788	11.8	5.11	15.28	1.84	0.644	17.5	5.11	7.41	2.26	0.517	31.8	5.11	5.73	2.69	0.570	35.2	5.11	5.73	3.12	0.670	33.1
12	5.11	30.15	0.00	0.973	9.5	5.11	21.10	1.84	0.812	13.1	5.11	12.09	2.26	0.652	21.4	5.1067	7.27	2.69	0.61	32.3	5.1067	5.73	3.1173	0.670	33.1
14						5.11	27.15	1.84	0.987	10.4	5.11	17.53	2.26	0.810	15.5	5.11	11.00	2.69	0.722	23.2	5.11	5.79	3.12	0.672	38.2
16						5.11	33.33	1.84	1.166	8.6	5.11	23.36	2.26	0.978	12.0	5.1067	15.65	2.69	0.86	17.1	5.1067	8.81	3.1173	0.759	27.8
18											5.11	29.41	2.26	1.153	9.7	5.1067	20.92	2.69	1.01	13.2	5.1067	12.83	3.1173	0.876	20.3
20											5.11	35.58	2.26	1.331	8.1	5.1067	26.59	2.69	1.17	10.6	5.1067	17.66	3.1173	1.015	15.4
22																5.1067	32.48	2.69	1.34	8.8	5.1067	23.03	3.1173	1.170	12.1
24																5.1067	38.53	2.69	1.52	7.5	5.1067	28.74	3.1173	1.335	9.9
26																					5.1067	34.65	3.1173	1.506	8.3
28																					5.1067	40.70	3.1173	1.681	7.1

ϕ16 mm x 1.3 mm 27.6 MPa   Rc =112.8/117.6 mm   PITCH =20.3±1.8 mm   D = 225.6/235.5 mm

	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2	129.7	145.6	0.0	1.2	159.5																				
4	129.7	145.6	0.0	1.2	159.5	129.7	145.6	46.6	1.6	168.0															
6	129.7	280.0	0.0	1.9	102.8	129.7	145.6	46.6	1.6	168.0	129.7	145.6	57.5	2.08	150.1										
8	129.7	441.1	0.0	2.7	69.5	129.7	252.2	46.6	2.2	112.1	129.7	145.6	57.5	2.08	150.1	129.7	145.6	68.3	2.53	156.5					
10	129.7	603.2	0.0	3.5	52.4	129.7	388.1	46.6	2.9	77.8	129.7	188.2	57.5	2.30	141.4	129.7	145.6	68.3	2.53	156.5	129.7	145.6	79.2	2.98	147.2
12	129.7	765.9	0.0	4.3	42.1	129.7	535.9	46.6	3.6	58.4	129.7	307.1	57.5	2.90	95.2	129.7	184.7	68.3	2.73	143.5	129.7	145.6	79.2	2.98	147.2
14						129.7	689.7	46.6	4.4	46.4	129.7	445.2	57.5	3.60	69.0	129.7	279.5	68.3	3.21	103.0	129.7	146.9	79.2	2.99	170.1
16						129.7	846.6	46.6	5.2	38.3	129.7	593.5	57.5	4.35	53.2	129.7	397.5	68.3	3.81	76.2	129.7	223.8	79.2	3.38	123.5
18											129.7	747.0	57.5	5.13	43.1	129.7	531.5	68.3	4.49	58.8	129.7	325.9	79.2	3.89	90.5
20											129.7	903.7	57.5	5.92	36.0	129.7	675.3	68.3	5.21	47.3	129.7	448.6	79.2	4.52	68.5
22																129.7	825.1	68.3	5.97	39.2	129.7	584.9	79.2	5.21	53.9
24																129.7	978.6	68.3	6.75	33.4	129.7	729.9	79.2	5.94	44.0
26																					129.7	880.2	79.2	6.70	36.9
28																					129.7	1033.9	79.2	7.48	31.7
																					0.00	0.00	0.00		





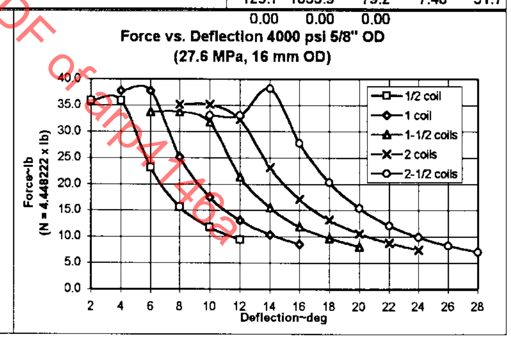


FIGURE A3 (Continued)

ϕ3/4" x .060 4000 psi — Rc = 5.25/5.50 in. — Pitch = 0.94±0.09 in. — D =10.50/11.01 in.

Deflection ~ deg	1/2 coil A±0.03 ~in	1/2 coil B±0.03 ~in	1/2 coil C±0.03 ~in	1/2 coil Weight ~lb	1/2 coil Force ~lb	1 coil A±0.03 ~in	1 coil B±0.03 ~in	1 coil C±0.03 ~in	1 coil Weight ~lb	1 coil Force ~lb	1-1/2 coils A±0.03 ~in	1-1/2 coils B±0.03 ~in	1-1/2 coils C±0.03 ~in	1-1/2 coils Weight ~lb	1-1/2 coils Force ~lb	2 coils A±0.03 ~in	2 coils B±0.03 ~in	2 coils C±0.03 ~in	2 coils Weight ~lb	2 coils Force ~lb	2-1/2 coils A±0.03 ~in	2-1/2 coils B±0.03 ~in	2-1/2 coils C±0.03 ~in	2-1/2 coils Weight ~lb	2-1/2 coils Force ~lb
2	6.09	6.84	0.00	0.457	52.3																				
4	6.09	6.84	0.00	0.457	52.3	6.09	6.84	2.20	0.629	55.0															
6	6.09	13.44	0.00	0.732	32.7	6.09	6.84	2.20	0.629	55.0	6.09	6.84	2.71	0.801	49.1										
8	6.09	21.12	0.00	1.052	22.1	6.09	12.13	2.20	0.849	35.5	6.09	6.84	2.71	0.801	49.1	6.0891	6.84	3.22	0.97	51.2					
10	6.09	28.85	0.00	1.373	16.7	6.09	18.66	2.20	1.121	24.7	6.09	9.14	2.71	0.896	44.6	6.09	6.84	3.22	0.972	51.2	6.09	6.84	3.73	1.144	48.2
12	6.09	36.60	0.00	1.696	13.4	6.09	25.73	2.20	1.415	18.5	6.09	14.88	2.71	1.136	30.0	6.0891	8.94	3.22	1.06	45.4	6.0891	6.84	3.7291	1.144	48.2
14						6.09	33.07	2.20	1.721	14.7	6.09	21.52	2.71	1.412	21.7	6.09	13.56	3.22	1.252	32.4	6.09	7.14	3.73	1.157	53.7
16						6.09	40.56	2.20	2.033	12.1	6.09	28.62	2.71	1.707	16.8	6.0891	19.27	3.22	1.49	24.0	6.0891	10.92	3.7291	1.314	38.7
18											6.09	35.96	2.71	2.013	13.6	6.0891	25.72	3.22	1.76	18.5	6.0891	15.91	3.7291	1.521	28.3
20											6.09	43.44	2.71	2.324	11.4	6.0891	32.62	3.22	2.05	14.9	6.0891	21.85	3.7291	1.769	21.4
22																6.0891	39.79	3.22	2.34	12.4	6.0891	28.42	3.7291	2.042	16.9
24																6.0891	47.13	3.22	2.65	10.5	6.0891	35.38	3.7291	2.332	13.8
26																					6.0891	42.57	3.7291	2.631	11.6
28																					6.0891	49.92	3.7291	2.937	10.0

ϕ19 mm x 1.5 mm 27.6 MPa — Rc =133.4/139.7 mm — PITCH =23.9±2.3 mm — D = 266.7/279.7 mm

Deflection ~ deg	1/2 coil A±0.8 ~mm	1/2 coil B±0.8 ~mm	1/2 coil C±0.8 ~mm	1/2 coil Weight ~N	1/2 coil Force ~N	1 coil A±0.8 ~mm	1 coil B±0.8 ~mm	1 coil C±0.8 ~mm	1 coil Weight ~N	1 coil Force ~N	1-1/2 coils A±0.8 ~mm	1-1/2 coils B±0.8 ~mm	1-1/2 coils C±0.8 ~mm	1-1/2 coils Weight ~N	1-1/2 coils Force ~N	2 coils A±0.8 ~mm	2 coils B±0.8 ~mm	2 coils C±0.8 ~mm	2 coils Weight ~N	2 coils Force ~N	2-1/2 coils A±0.8 ~mm	2-1/2 coils B±0.8 ~mm	2-1/2 coils C±0.8 ~mm	2-1/2 coils Weight ~N	2-1/2 coils Force ~N
2	154.7	173.7	0.0	2.0	232.4																				
4	154.7	173.7	0.0	2.0	232.4	154.7	173.7	55.9	2.8	244.6															
6	154.7	341.4	0.0	3.3	145.2	154.7	173.7	55.9	2.8	244.6	154.7	173.7	68.8	3.56	218.6										
8	154.7	536.4	0.0	4.7	98.3	154.7	308.2	55.9	3.8	158.1	154.7	173.7	68.8	3.56	218.6	154.7	173.7	81.8	4.32	227.7					
10	154.7	732.7	0.0	6.1	74.2	154.7	473.8	55.9	5.0	109.7	154.7	232.1	68.8	3.99	198.4	154.7	173.7	81.8	4.32	227.7	154.7	173.7	94.7	5.09	214.4
12	154.7	929.5	0.0	7.5	59.5	154.7	653.5	55.9	6.3	82.3	154.7	378.1	68.8	5.05	133.3	154.7	227.0	81.8	4.71	201.8	154.7	173.7	94.7	5.09	214.4
14						154.7	840.0	55.9	7.7	65.4	154.7	546.7	68.8	6.28	96.6	154.7	344.3	81.8	5.57	144.2	154.7	181.5	94.7	5.14	238.9
16						154.7	1030.2	55.9	9.0	54.0	154.7	727.0	68.8	7.59	74.7	154.7	489.5	81.8	6.63	106.6	154.7	277.4	94.7	5.84	172.3
18											154.7	913.4	68.8	8.95	60.5	154.7	653.4	81.8	7.82	82.3	154.7	404.1	94.7	6.77	125.9
20											154.7	1103.3	68.8	10.34	50.7	154.7	828.6	81.8	9.10	66.2	154.7	555.1	94.7	7.87	95.3
22																154.7	1010.7	81.8	10.43	55.0	154.7	721.9	94.7	9.08	75.2
24																154.7	1197.1	81.8	11.78	46.9	154.7	898.6	94.7	10.37	61.4
26																					154.7	1081.4	94.7	11.70	51.6
28																					154.7	1268.0	94.7	13.06	44.4

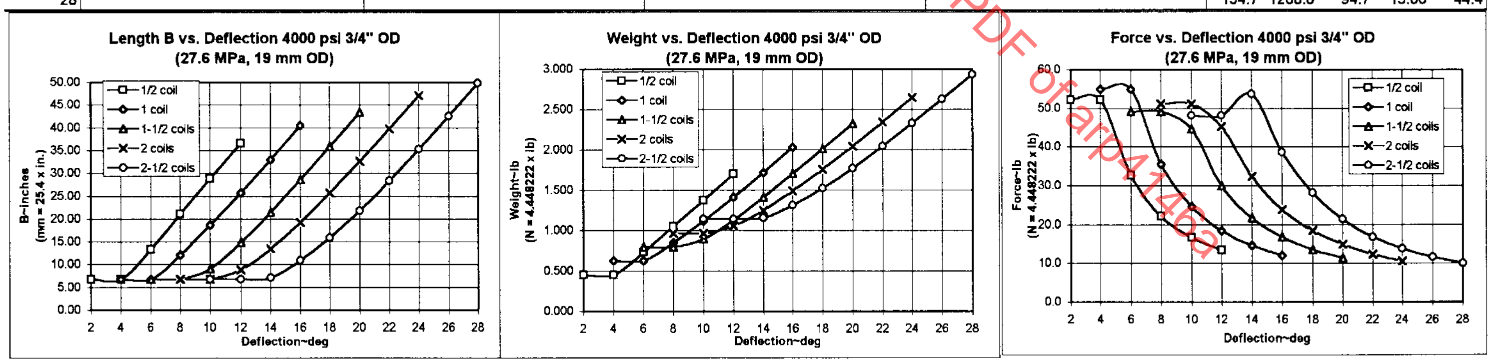


FIGURE A3 (Continued)