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An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP4146 REV. C

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Superseding ARP4146B

Coiled Tubing – Titanium Alloy, Hydraulic Applications, Aerospace

RATIONALE

ARP4146C corrects an equation in 7.1.2.

TABLE OF CONTENTS

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) addresses the design, installation, and testing of coiled tube assemblies using Ti-3Al-2.5V cold worked, stress relieved (CWSR) tubing per AMS4945. It specifically details five different configurations of coiled tubing.

The configurations detailed herein 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 the life of each unique design.

NOTE: For information on design of coiled tube assemblies using CRES steel tubing, see ARP584.

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.

1.2 Field of Application

The use of coiled tubes is encouraged in the design of hydraulic systems per AS5440 or ARP4752/ARP4925, and for pneumatic systems per MIL-P-5518 when standard flexible hoses are not feasible due to installation constraints, compliance limitations, and effusion requirements.

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 International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP584 Coiled Tubing - Corrosion Resistant Steel, Hydraulic Applications, Aerospace

AIR1379 Prestressing (Autofrettaging) of Hydraulic Tubing Lines

AS4076 Contractile Strain Ratio Testing of Titanium Hydraulic Tubing

AS4401 Separable Fittings, Permanent Fittings, Tubing, Fluid Systems, 8000 psi, Qualification Test Standard for

AS4467 Standardization, Hydraulic Tube Walls

ARP4752 Aerospace - Design and Installation of Commercial Transport Aircraft Hydraulic Systems

ARP4925 Aerospace - Design and Installation of Commercial Transport Helicopter Hydraulic Systems

AS5440 Hydraulic Systems, Military Aircraft, Design and Installation, Requirements For

AMS4945 Titanium Alloy Tubing, Seamless, Hydraulic, 3Al - 2.5V, Controlled Contractile Strain Ratio, Cold Worked, Stress Relieved

2.2 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-9495, https://assist.daps.dla.mil/quicksearch/.

MIL-P-5518 Pneumatic Systems, Aircraft, Design and Installation, General Requirements for

MMPDS Metallic Materials Properties Development and Standardization

3. CONFIGURATIONS

There are five configurations detailed in this ARP, which are as follows:

a. Style A - Helical Torsion Configuration

b. Style B - Torsion Tube Configuration

c. Style C - Helical Compression/Extension Configuration

d. Style D – Tri-Coil Compression/Extension Configuration

e. Style E- Oval Compression/Extension Configuration

Each configuration is described in the following sections.

3.1 Style A - Helical Torsion Configuration

This configuration (Figure 1) typically consists of a 540 degree (1-1/2 coil) helical coil of tubing with a straight section projecting from each end of the coil.

The upper illustration in Figure 1 shows an installation with the tubing coming from the rod end of the actuator and the coiled tubing not only provides the required flexibility, but also enables the direction of the tube routing to be reversed. The bottom illustration shows an installation where the tubing is coming directly on to the actuator's port.

In the 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 degrees (1/2 coil) up to 900 degrees (2-1/2 coils) where the angles quoted are the total angles through which the tubing is bent in the manufacture of each coil.

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 degrees.

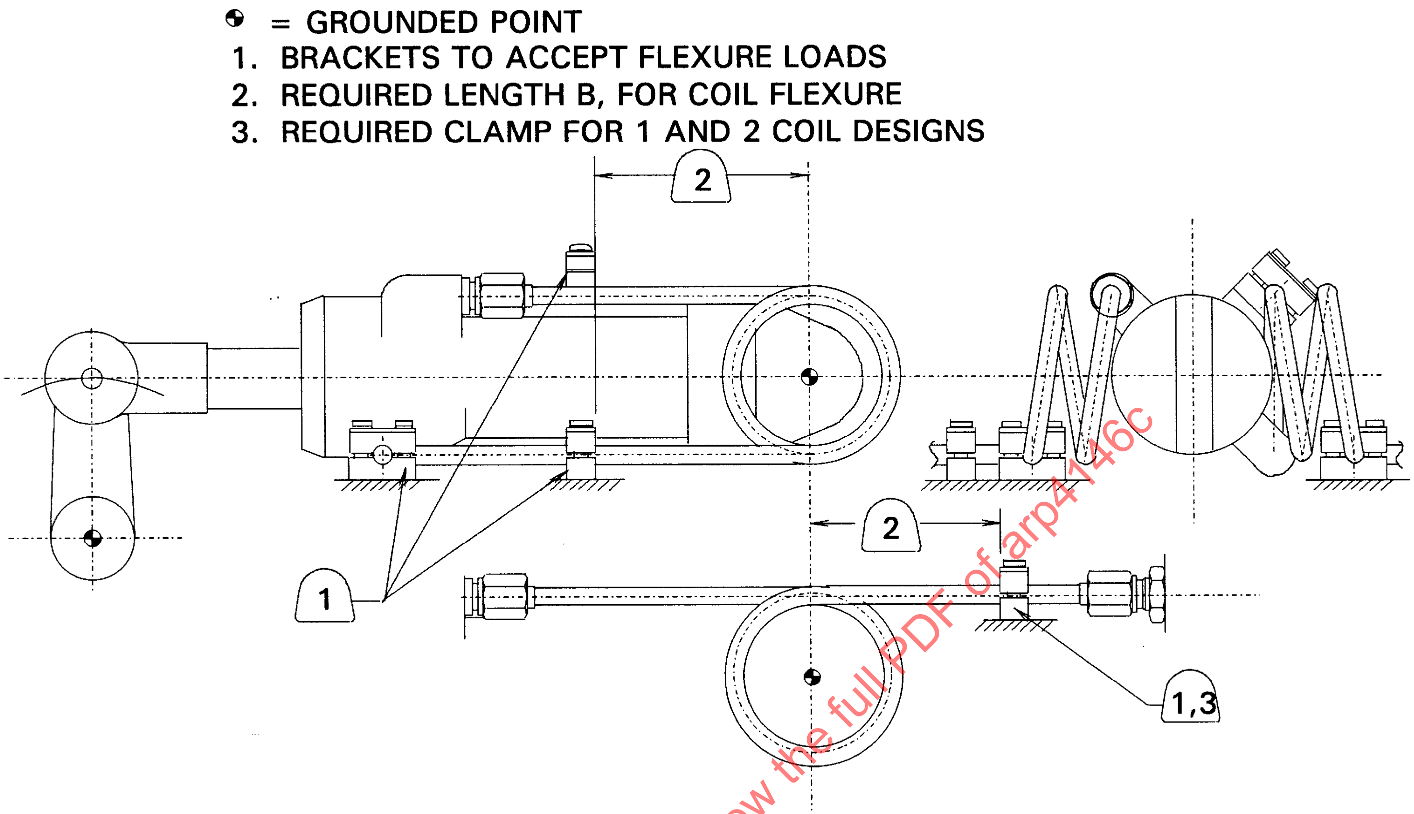


FIGURE 1 - STYLE A - HELICAL TORSION CONFIGURATION

3.2 Style B - Torsion Tube Configuration

This configuration (Figure 2) consists of three straight sections separated by two 90 degrees 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.

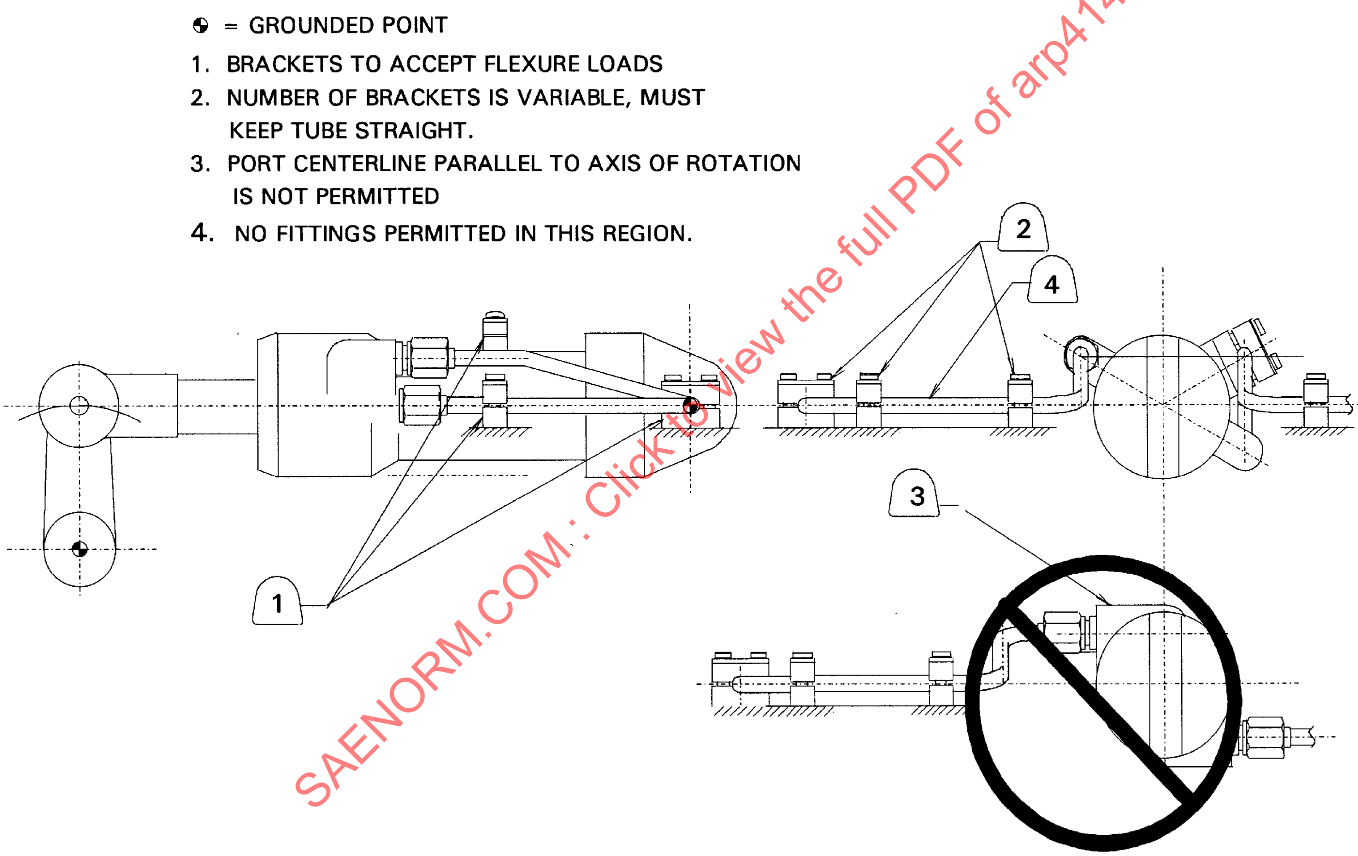


FIGURE 2 - STYLE B - TORSION TUBE CONFIGURATION

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.

◉ = GROUNDED POINT

1. COILS ARE AT MINIMUM LENGTH WITH ACTUATOR AT LENGTH LR.
2. COIL COMPRESSION, DELTA = .5556*(LE - LR).
3. COILS ARE COMPRESSED TO 0.0556*DELTA WITH ACTUATOR AT NEUTRAL.
4. COILS EXTEND 0.4444*(LE - LR).
5. COILS ARE AT MAXIMUM EXTENSION WITH ACTUATOR AT LE.

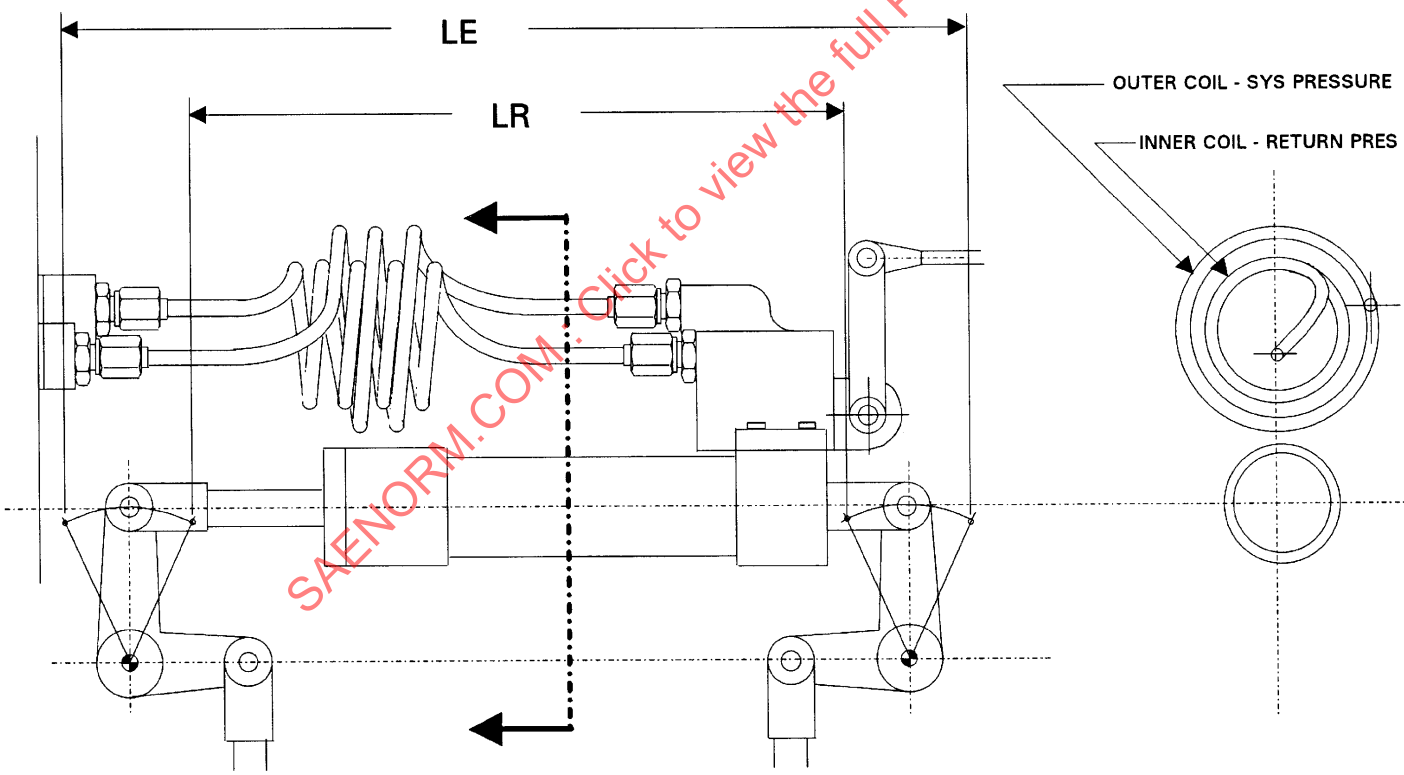


FIGURE 3 - STYLE C - HELICAL COMPRESSION/EXTENSION CONFIGURATION

3.4 Style D - Tri-Coil Compression/Extension 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.

⊕ = 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.

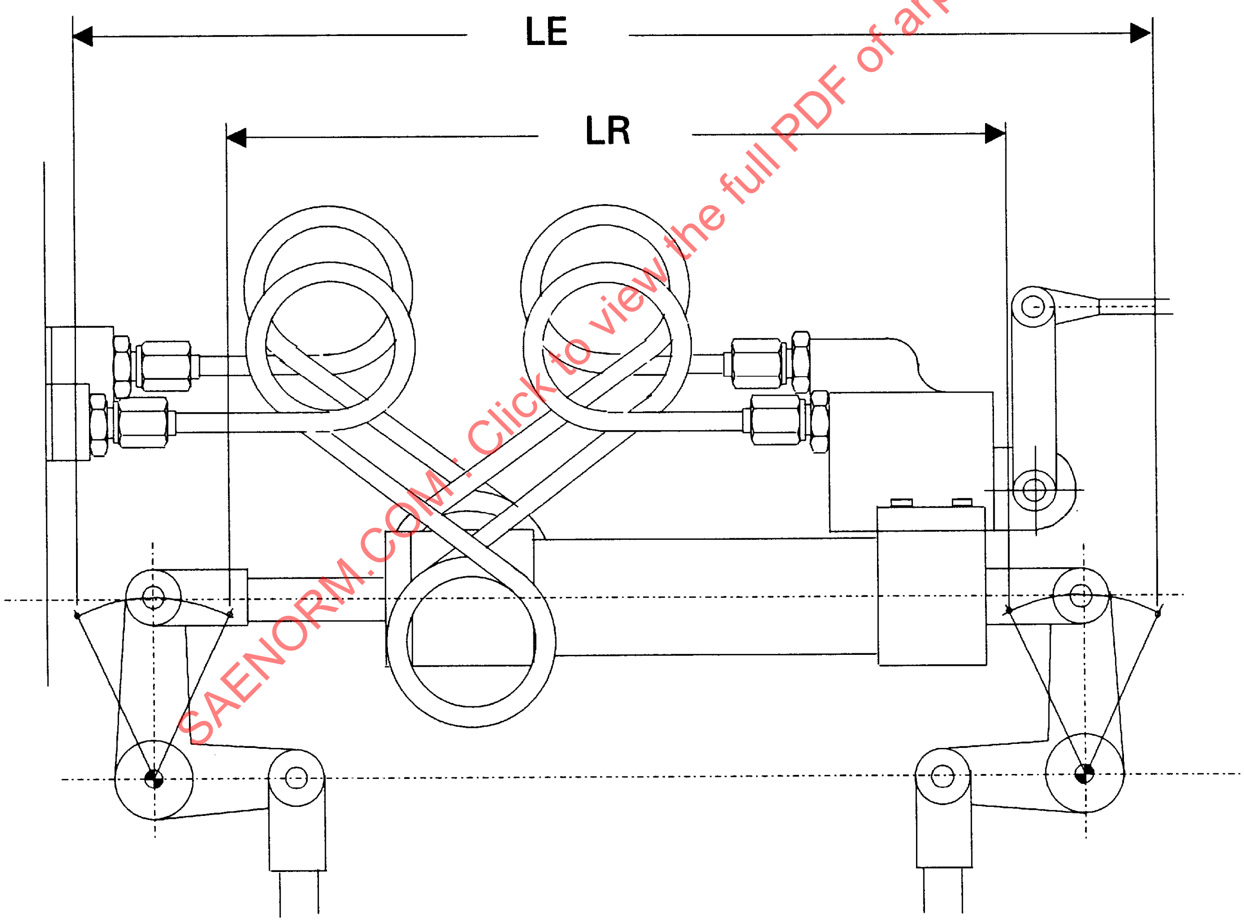


FIGURE 4 - STYLE D - TRI-COIL COMPRESSION/EXTENSION CONFIGURATION

3.5 Style E - Oval Compression/Extension 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.

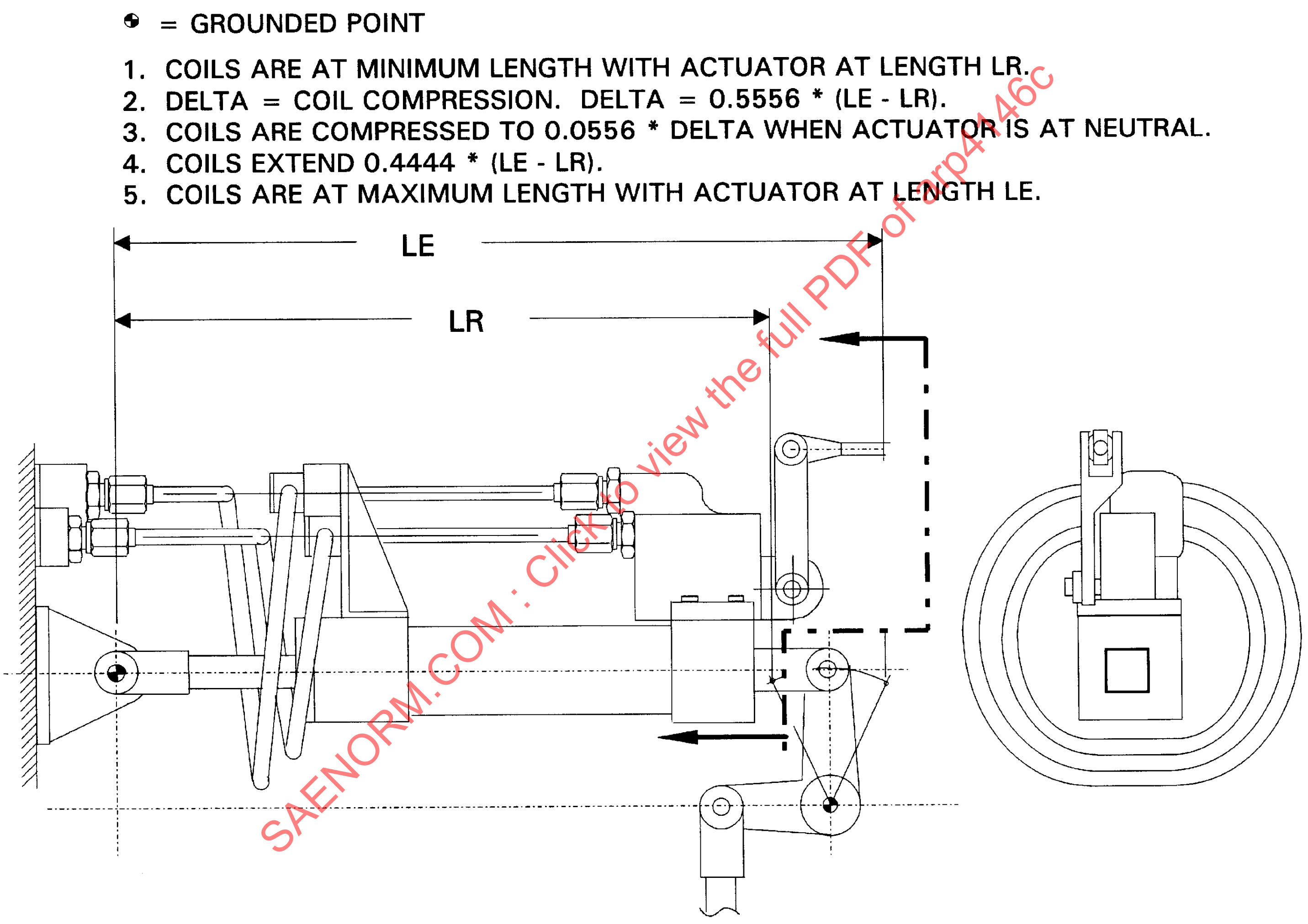


FIGURE 5 - STYLE E - OVAL HELICAL COMPRESSION/EXTENSION CONFIGURATION

4. MATERIAL PROPERTIES

The recommended material is seamless titanium alloy tubing, Ti-3Al-2.5V in the CWSR condition in accordance with AMS4945 or equivalent.

4.1 Basic Allowables

Room temperature allowables for this material are:

a. Ultimate tensile strength, F_{tu} (min): 125 000 psi (862 MPa)

b. Yield tensile strength, F_{ty} (min): 105 000 psi (724 MPa)

c. Elastic modulus, E: 15 000 000 psi (103 421 MPa)

d. Torsion modulus, G: 5 680 000 psi (39 162 MPa)

e. Poisson's ratio, μ: 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. This is achieved by multiplying 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 scatter band 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 should be prepared using the low end of the scatter band (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 non failure 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 anisotropy or directional properties in finished tubing. These directional properties manifest themselves as excessive thinning or the 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 AMS4945) 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, including:

a. Von-Mises Distortion Energy Failure Theory for loading in multiple axes.

b. Finite Element Analysis (FEA) is another technique for stress analysis of the sometimes irregular configurations required of coiled tubing. Any FEA software that is used 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. Any combinations of torsion and linear loading should be avoided unless specifically addressed in the qualification testing of coiled tube designs.

7. FABRICATION

7.1 Style A

Style A coiled tubing may be fabricated using one of several methods of forming the coils. The 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:

$$\text{Ovality} = \frac{(OD_{Max} - OD_{Min}) \times 100}{OD_{Nominal}} \quad \text{(Eq. 1)}$$

7.1.1 Conventional Tooling

The conventional die block which contains a semicircular shaped groove around 180 to 270 degrees of its external surface must be replaced by a similar block containing a groove which spirals through 600 degrees (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. 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 coiled tubing 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.

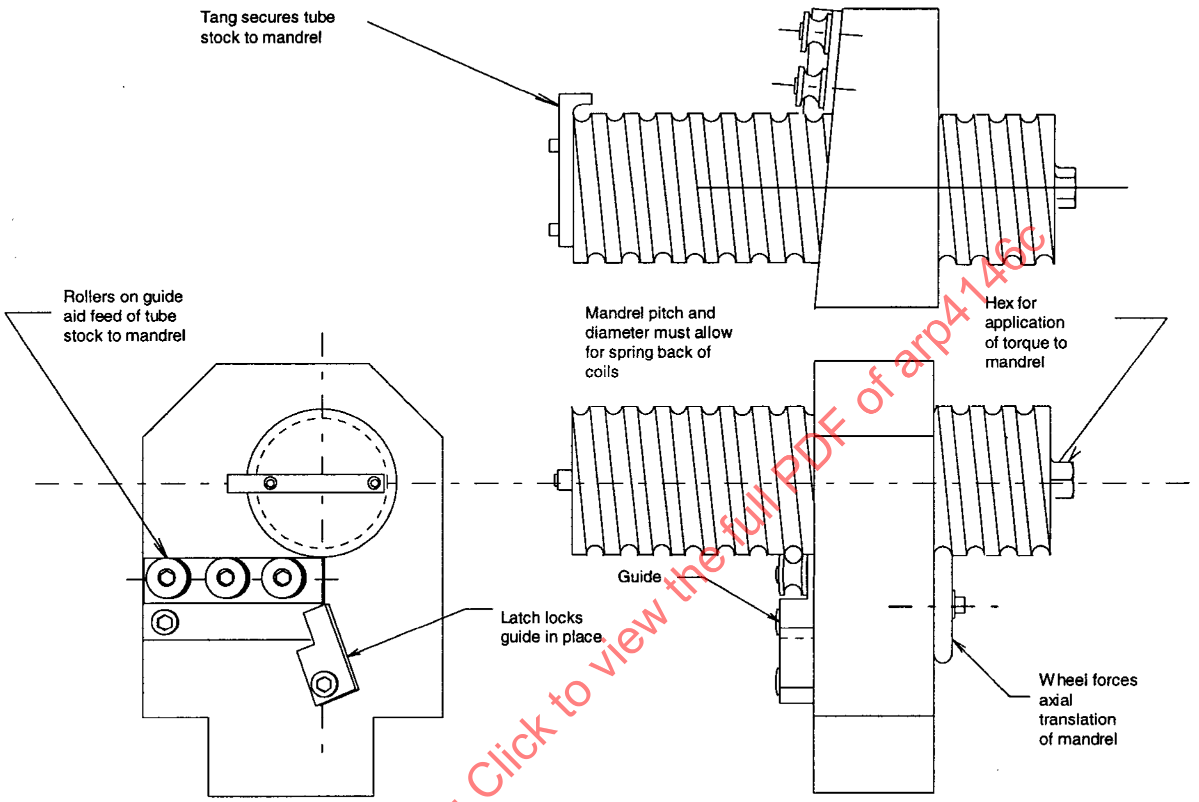


FIGURE 6 - SPIRAL MANDREL COILING TOOL

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:

Da = arbor diameter

Ftu = ultimate tensile stress allowable

E = modulus of elasticity

Do = tubing OD

Di = tubing ID

Ds = coil OD

and

$$R = \frac{\sqrt{2}}{2} \times \sqrt{Do^2 + Di^2} \qquad \text{(Eq. 3)}$$

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

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.

7.2 Style B

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

7.3 Style C

Style C coiled tubing 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 coiled tubing may be formed using any of the tooling described in 7.1.1 through 7.1.3.

7.5 Style E

Style E coiled tubing 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 the mandrels may be required to prevent linear scratches in the tube wall during forming.

7.7 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 the 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.

8. 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:

a. Misalignment when the component operates or,

b. 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.

8.1 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.

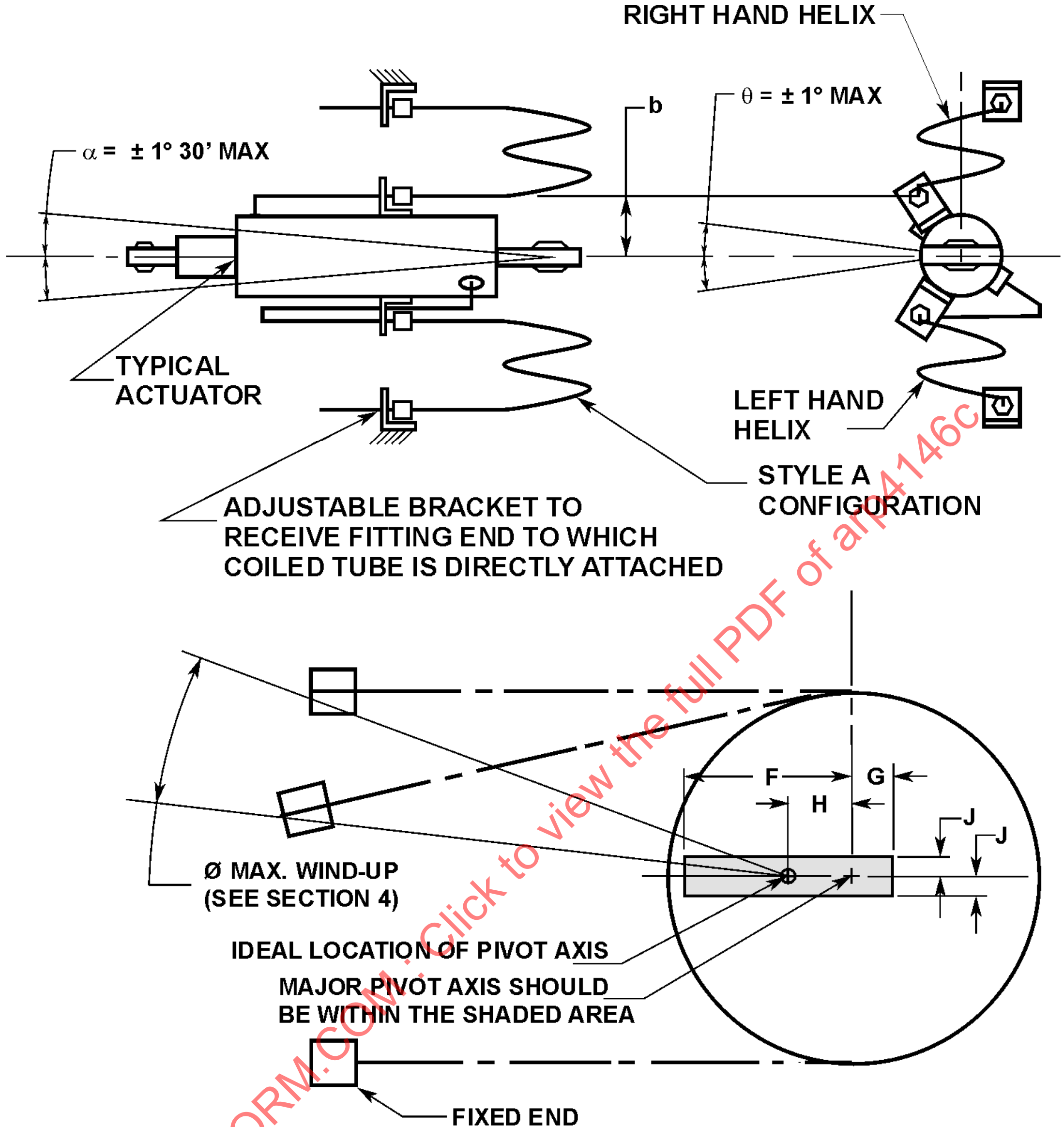
The helix should be located as close as possible to the moving component to minimize the effects of misalignment. The coil should be designed for rotation of 10 to 20% more than the nominal deflection to allow for misalignment or rotation of the actuator during operation. The percentage used should be 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 an integer such as one or two, the moment arms fall approximately in line with each other in a 360 or 720 degree relationship. 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 shows an example of this design variant with only one arm clamped.

If the additional clamping is not provided, the geometry results in compression and extension loads into the coil and also the fittings may be out of alignment when they are installed in the actuator ports. This could lead to fitting leakage or early fatigue failure of the tube.



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 COILED TUBE INSTALLATION

8.2 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.

8.3 Style C Installation

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.

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.

8.4 Style D Installation

The tri-coil 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.

8.5 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.

9. 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.

Techniques that can be adapted for damping coiled tubing are detailed in the following section.

9.1 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.

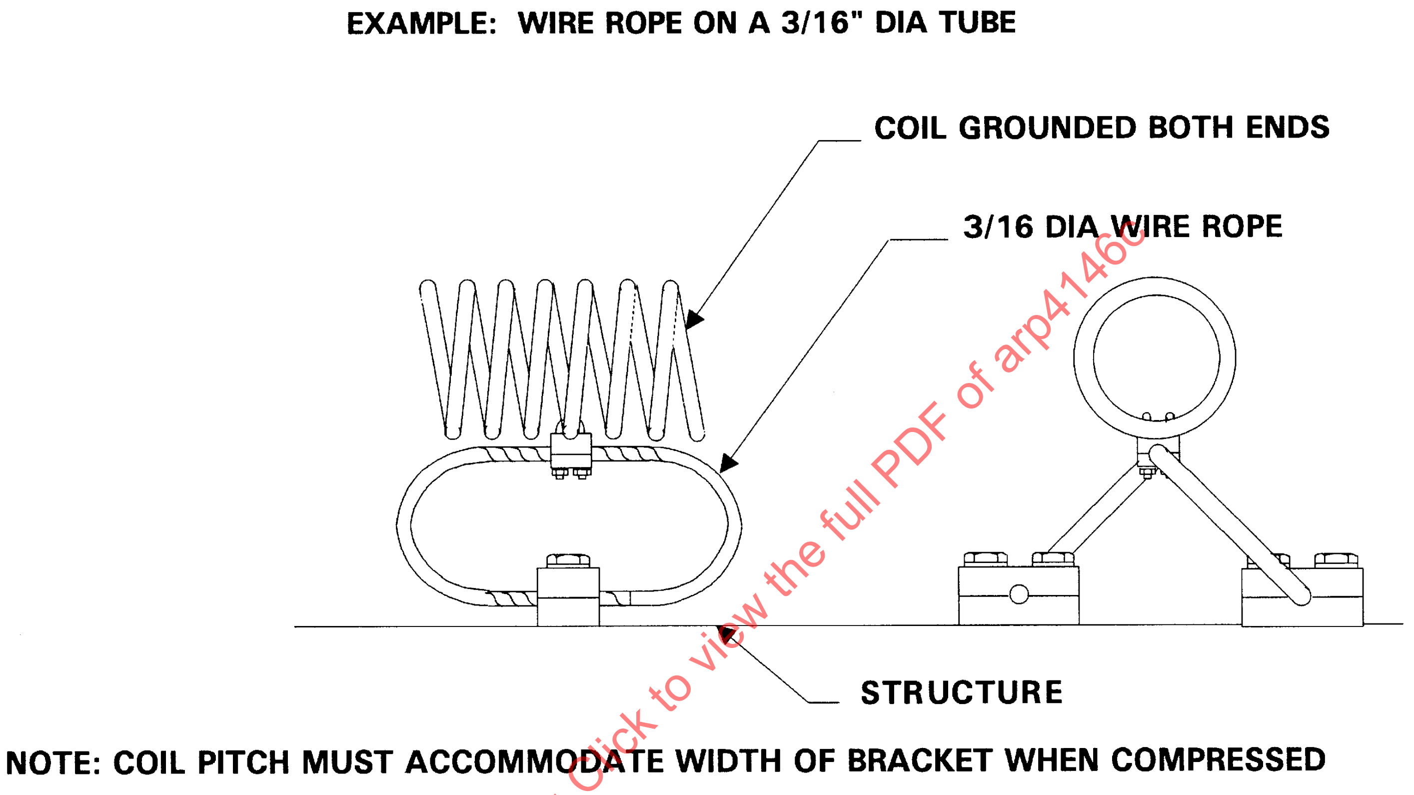


FIGURE 8 - CRES WIRE ROPE DAMPER

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.

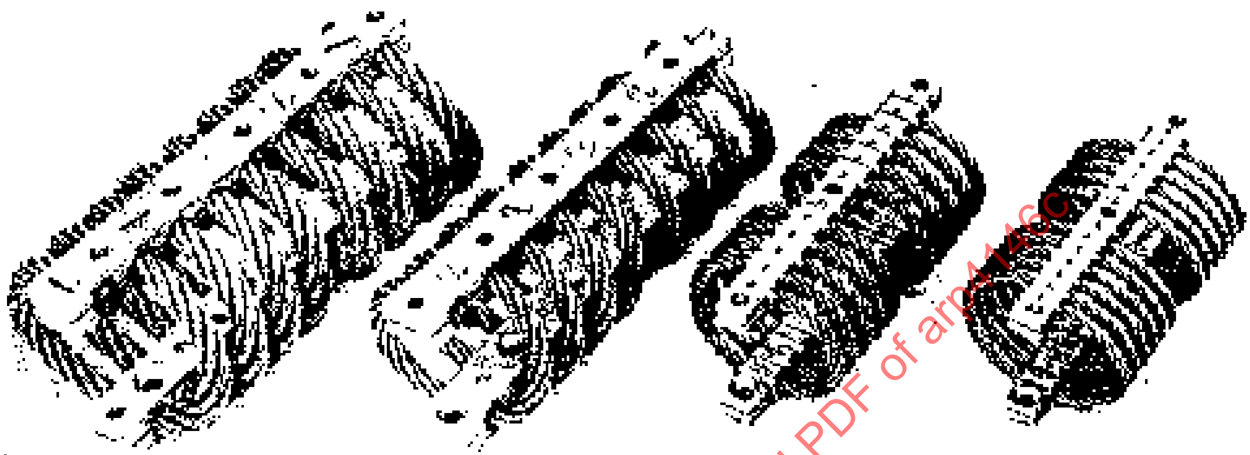
9.2 Ties and Loops

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.

9.3 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 has been tested 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.



Each helical cable has specific response characteristics determined by the diameter of the wire rope, the number of strands, the cable twist or lay, and the number of cables per section. Inherent damping is provided by flexure hysteresis, i.e., the rubbing and sliding friction between the strands of the wire rope.

FIGURE 9 - COMMERCIAL WIRE ROPE DAMPER

10. NOTES

10.1 Document Change Identification

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE SUBCOMMITTEE A-6C4, TUBING PANEL OF
COMMITTEE A-6, AEROSPACE ACTUATION, CONTROL AND FLUID POWER SYSTEMS

APPENDIX A - DESIGN DATA FOR STYLE A CONFIGURATION

A.1 DESIGN SPECIFICATIONS

A.1.1 Basis

These 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 degrees, 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 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. All of the designs are designed for the following spectrum with a scatter factor of four:

TABLE A1 - GENERIC SPECTRUM OF DEFLECTION VERSUS NUMBER OF CYCLES

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 A21, 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.

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

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

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

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

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

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

Refer to Figures A2 to A21

There is a figure for each design pressure, 3000, 4000, 5000, and 8000 psi (20.7, 27.6, 34.5, and 55.2 MPa), and for the following tube sizes.

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 for one of the following tube sizes.

- ¼ in (6 mm)
- 3/8 in (10 mm)
- ½ in (13 mm)
- 5/8 in (16 mm)
- ¾ in (19 mm)

A.2.3 Example of Use of Design Data Figures

Assume the following design case:

- Operating pressure = 4000 psi (27.6 MPa)
- Deflection = 9 degrees
- Tube diameter = 3/8 in (6 mm)
- 50 000 cycles full stroke deflection
- Installation requires both tube fittings to be adjacent

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

b. Referring to Figure A8 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 degrees deflection. (To obtain data for odd degrees, average the values for the even data below and above the odd requirement.)

TABLE A2 - WEIGHT-LB (N)

En	8 degrees	10 degrees	9 degrees
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)

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

d. 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 degrees 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 degrees 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 degrees deflection would be between 1.5 coils and 2 coils as follows:

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

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

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

To compute dimension C:

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

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

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

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

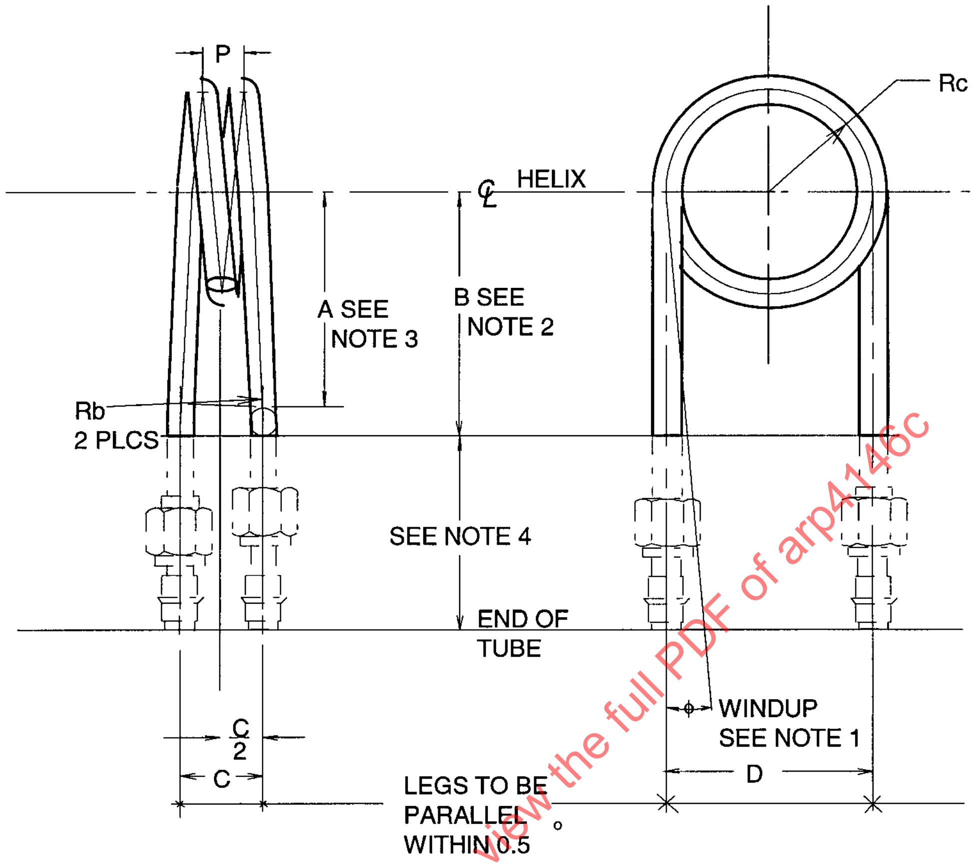


FIGURE A1 - STYLE A DESIGN DIMENSIONS

Figures A2 through A21 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 degrees.

	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

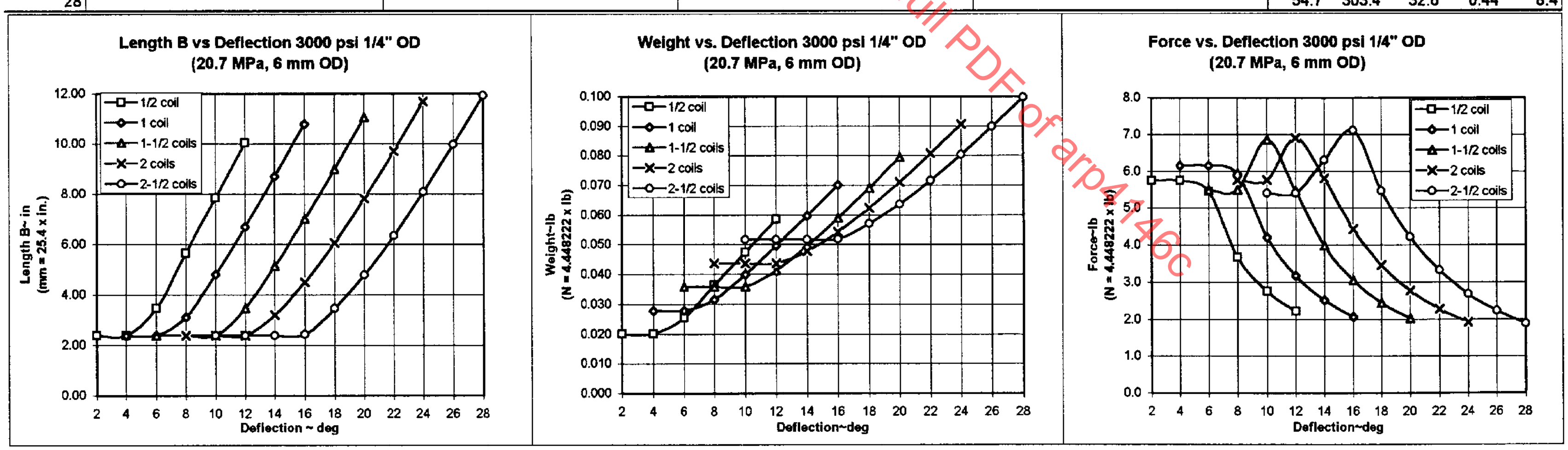
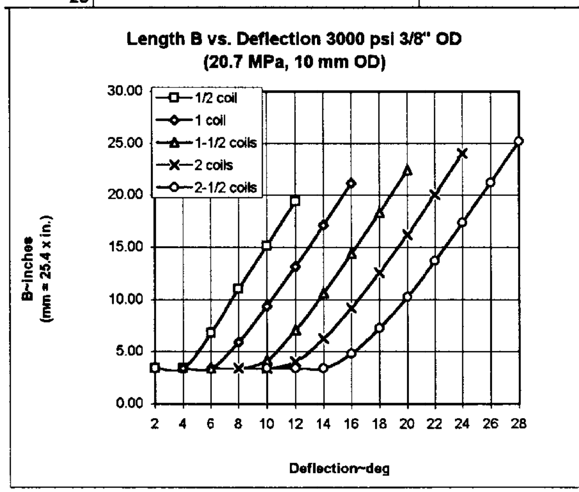
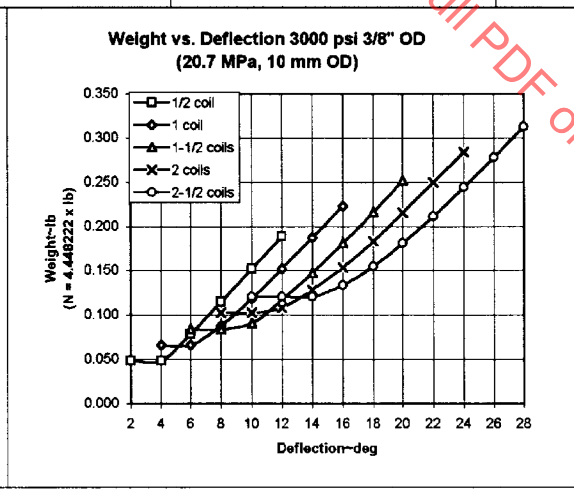


FIGURE A2 - DESIGN DATA FOR 3000 PSI - Ø1/4 IN (Ø6 MM - 20.7 MPA) STYLE A

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





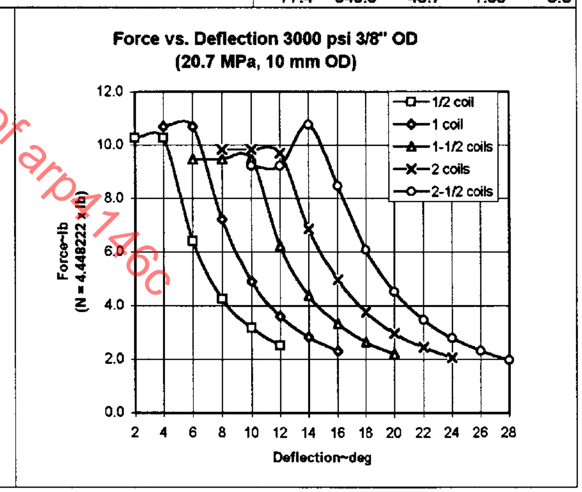


FIGURE A3 - DESIGN DATA FOR 3000 PSI - Ø3/8 IN (Ø10 MM - 20.7 MPA) STYLE A

Deflection ~ deg	ϕ1/2" x .034 3000 psi — 1/2 coil A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	Rc = 3.50/3.62 in. — 1 coil A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	Pitch = 0.63±0.06 in. — 1-1/2 coils A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	D = 7.00/7.27 in. — 2 coils A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	2-1/2 coils 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

Deflection ~ deg	ϕ13 mm x 0.86 mm 20.7 MPa — 1/2 coil A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	Rc =88.9/92.0 mm — 1 coil A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	PITCH =16.0±1.5 mm — 1-1/2 coils A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	D = 177.8/184.7 mm — 2 coils A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	2-1/2 coils 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

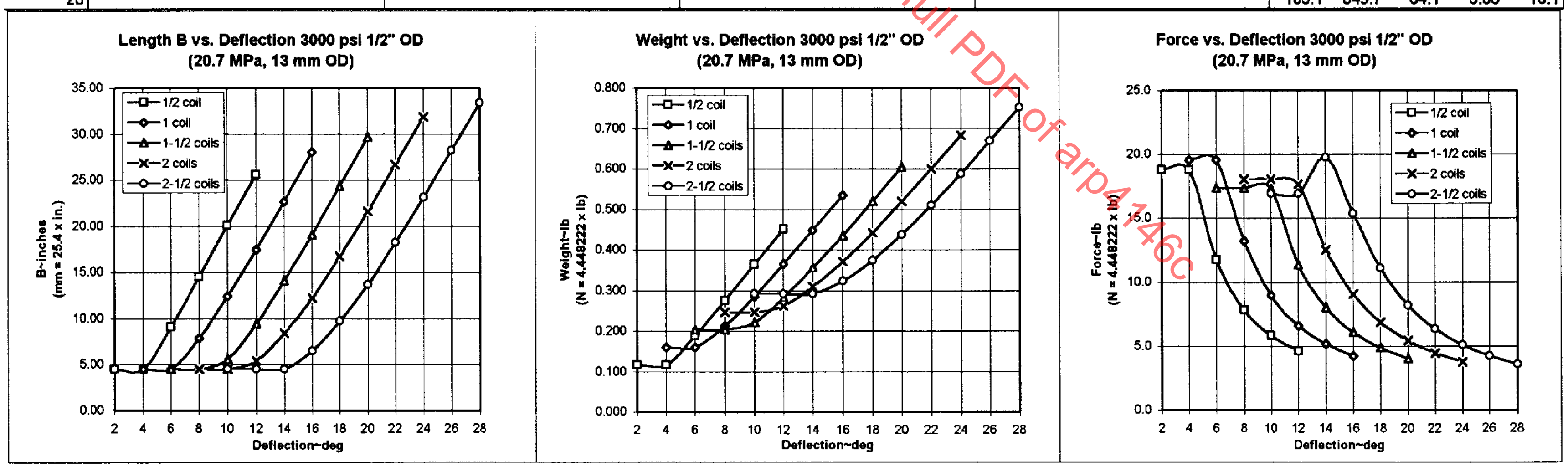
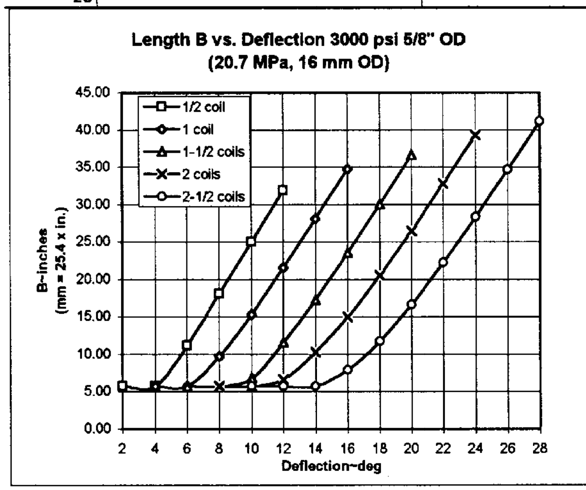
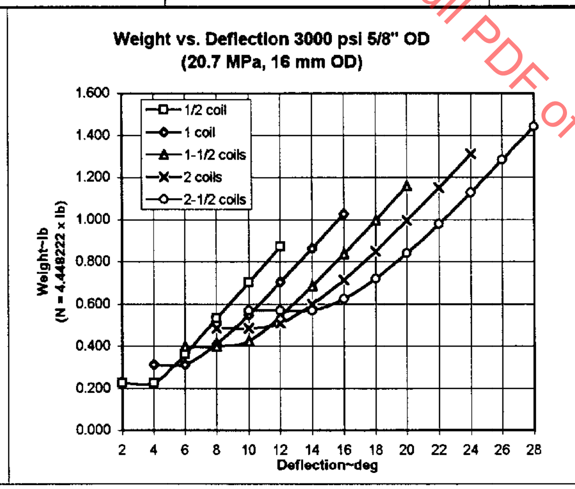


FIGURE A4 - DESIGN DATA FOR 3000 PSI - Ø1/2 IN (Ø13 MM - 20.7 MPA) STYLE A

Deflection ~ deg	ϕ5/8" x .042 3000 psi 1/2 coil A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	Rc = 4.44/4.63 in. 1 coil A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	Pitch = 0.80±0.07 in. 1-1/2 coils A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	D = 8.88/9.27 in. 2 coils A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb	2-1/2 coils 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

Deflection ~ deg	ϕ16 mm x 1.07 mm 20.7 MPa 1/2 coil A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	Rc =112.8/117.6 mm 1 coil A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	PITCH =20.3±1.8 mm 1-1/2 coils A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	D = 225.6/235.5 mm 2 coils A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N	2-1/2 coils 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





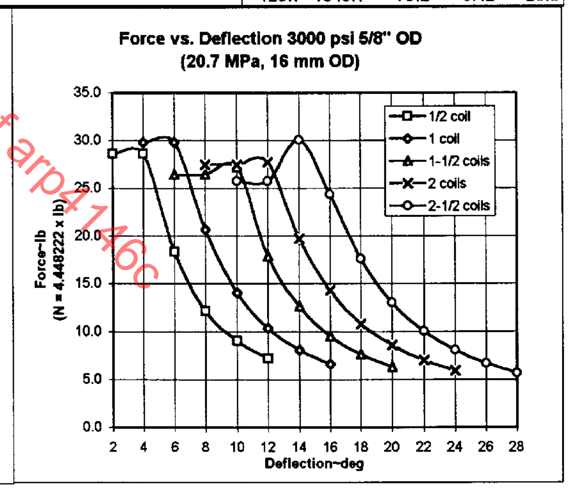
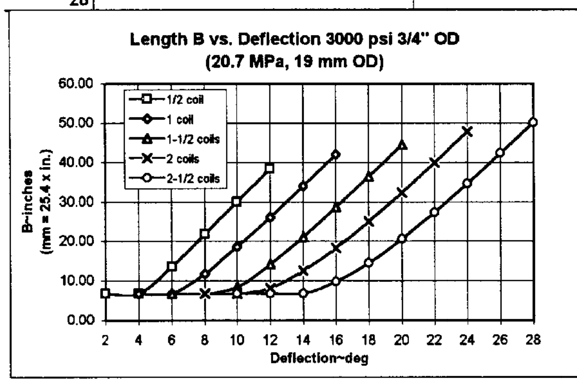
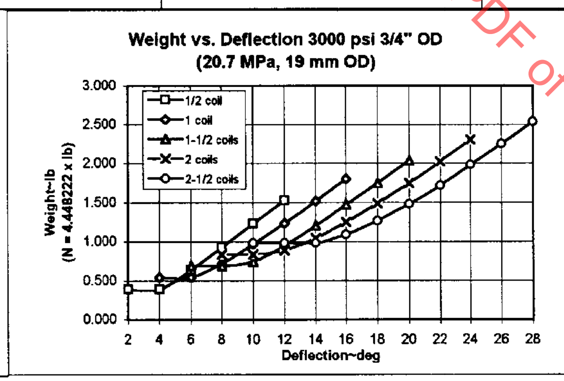


FIGURE A5 - DESIGN DATA FOR 3000 PSI - Ø5/8 IN (Ø16 MM - 20.7 MPA) STYLE A

	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





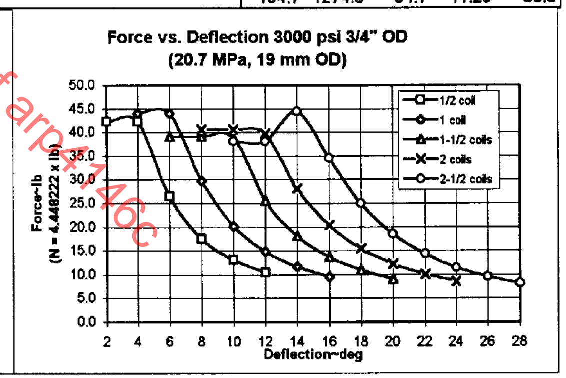
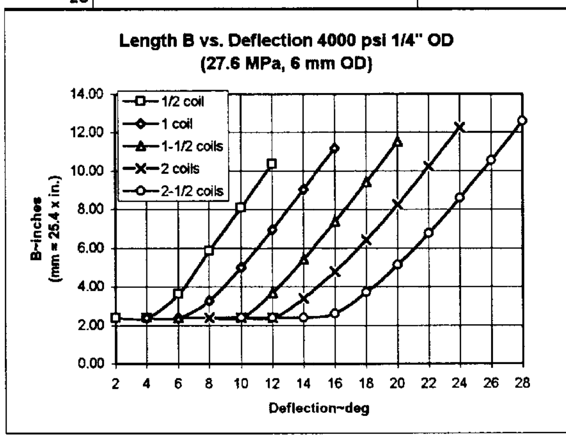
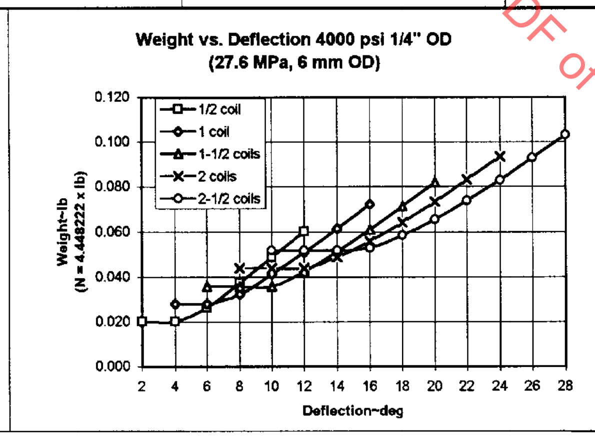


FIGURE A6 - DESIGN DATA FOR 3000 PSI - Ø3/4 IN (Ø19 MM - 20.7 MPA) STYLE A

	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





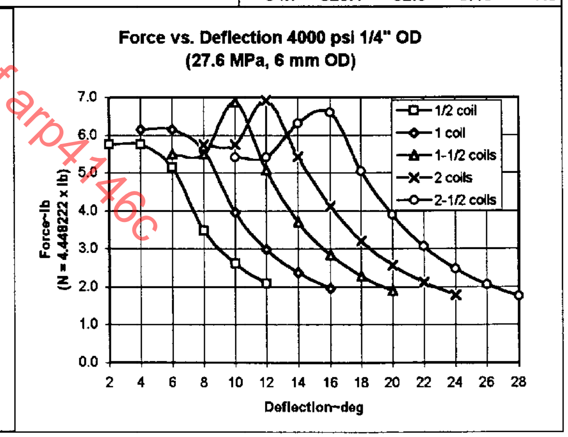


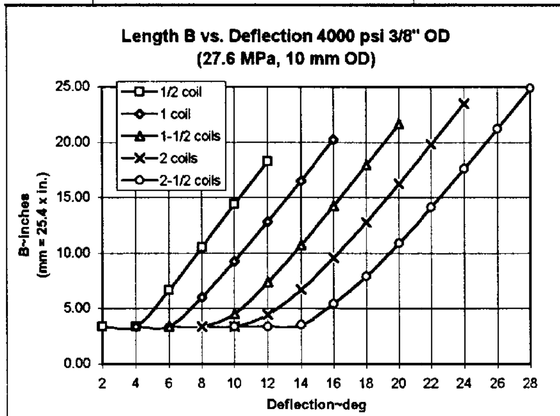
FIGURE A7 - DESIGN DATA FOR 4000 PSI - Ø1/4 IN (Ø6 MM - 27.6 MPA) STYLE A

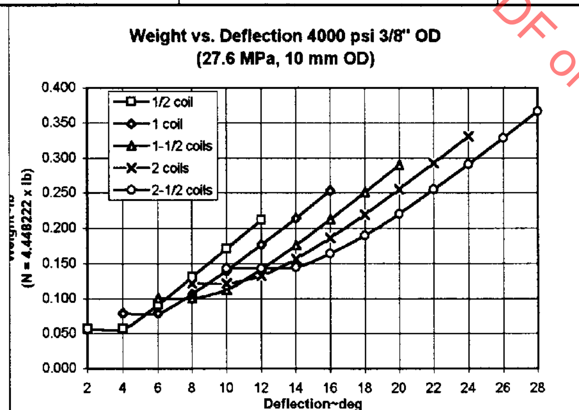
ϕ3/8" x .030 4000 psi | Rc = 2.63/2.72 in. | PITCH = 0.49±0.04 in. | D = 5.26/5.39 in.

Deflection	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
~ 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

Deflection	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
~ 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





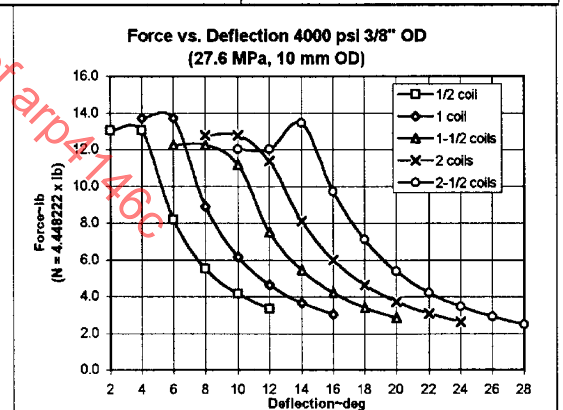


FIGURE A8 - DESIGN DATA FOR 4000 PSI - Ø3/8 IN (Ø10 MM - 27.6 MPA) STYLE A

	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

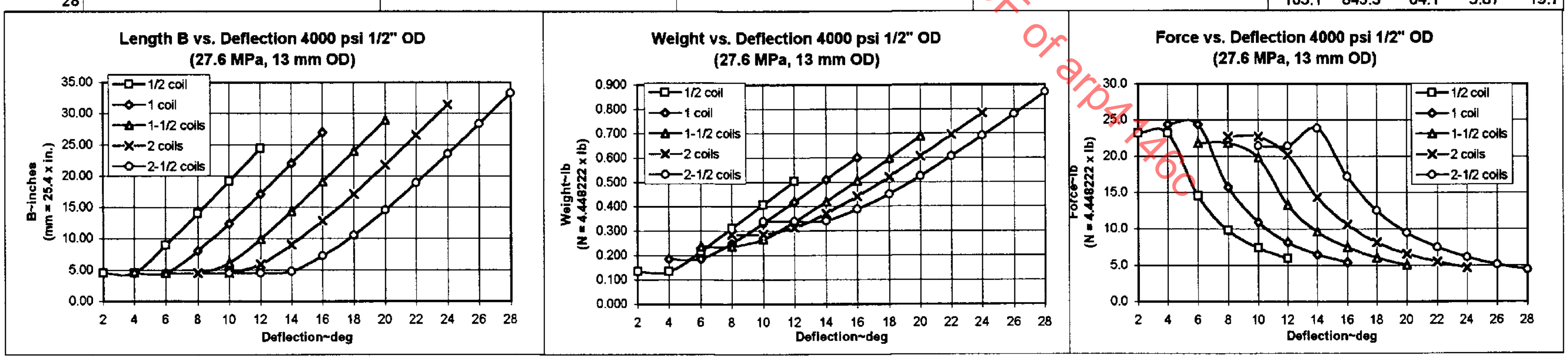


FIGURE A9 - DESIGN DATA FOR 4000 PSI - Ø1/2 IN (Ø13 MM - 27.6 MPA) STYLE A

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

Deflection ~ deg	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
6	5.11	11.02	0.00	0.420	23.1
8	5.11	17.36	0.00	0.603	15.6
10	5.11	23.75	0.00	0.788	11.8
12	5.11	30.15	0.00	0.973	9.5
14					
16					
18					
20					
22					
24					
26					
28					

1 coil

Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2					
4	5.11	5.73	1.84	0.368	37.8
6	5.11	5.73	1.84	0.368	37.8
8	5.11	9.93	1.84	0.489	25.2
10	5.11	15.28	1.84	0.644	17.5
12	5.11	21.10	1.84	0.812	13.1
14	5.11	27.15	1.84	0.987	10.4
16	5.11	33.33	1.84	1.166	8.6
18					
20					
22					
24					
26					
28					

1-1/2 coils

Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2					
4					
6	5.11	5.73	2.26	0.469	33.7
8	5.11	5.73	2.26	0.469	33.7
10	5.11	7.41	2.26	0.517	31.8
12	5.11	12.09	2.26	0.652	21.4
14	5.11	17.53	2.26	0.810	15.5
16	5.11	23.36	2.26	0.978	12.0
18	5.11	29.41	2.26	1.153	9.7
20	5.11	35.58	2.26	1.331	8.1
22					
24					
26					
28					

2 coils

Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2					
4					
6					
8	5.1067	5.73	2.69	0.57	35.2
10	5.11	5.73	2.69	0.570	35.2
12	5.1067	7.27	2.69	0.61	32.3
14	5.11	11.00	2.69	0.722	23.2
16	5.1067	15.65	2.69	0.86	17.1
18	5.1067	20.92	2.69	1.01	13.2
20	5.1067	26.59	2.69	1.17	10.6
22	5.1067	32.48	2.69	1.34	8.8
24	5.1067	38.53	2.69	1.52	7.5
26					
28					

2-1/2 coils

Deflection ~ deg	A±0.03 ~in	B±0.03 ~in	C±0.03 ~in	Weight ~lb	Force ~lb
2					
4					
6					
8					
10	5.11	5.73	3.12	0.670	33.1
12	5.1067	5.73	3.1173	0.670	33.1
14	5.11	5.79	3.12	0.672	38.2
16	5.1067	8.81	3.1173	0.759	27.8
18	5.1067	12.83	3.1173	0.876	20.3
20	5.1067	17.66	3.1173	1.015	15.4
22	5.1067	23.03	3.1173	1.170	12.1
24	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

Deflection ~ deg	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
6	129.7	280.0	0.0	1.9	102.8
8	129.7	441.1	0.0	2.7	69.5
10	129.7	603.2	0.0	3.5	52.4
12	129.7	765.9	0.0	4.3	42.1
14					
16					
18					
20					
22					
24					
26					
28					

1 coil

Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2					
4	129.7	145.6	46.6	1.6	168.0
6	129.7	145.6	46.6	1.6	168.0
8	129.7	252.2	46.6	2.2	112.1
10	129.7	388.1	46.6	2.9	77.8
12	129.7	535.9	46.6	3.6	58.4
14	129.7	689.7	46.6	4.4	46.4
16	129.7	846.6	46.6	5.2	38.3
18					
20					
22					
24					
26					
28					

1-1/2 coils

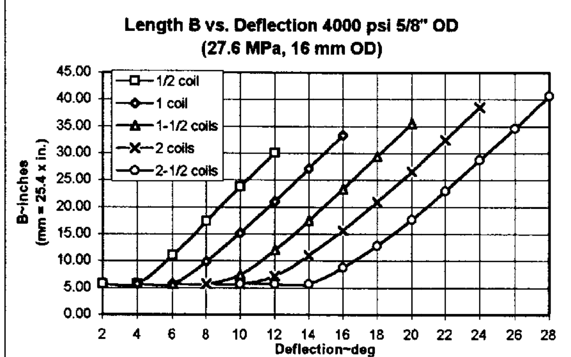
Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2					
4					
6	129.7	145.6	57.5	2.08	150.1
8	129.7	145.6	57.5	2.08	150.1
10	129.7	188.2	57.5	2.30	141.4
12	129.7	307.1	57.5	2.90	95.2
14	129.7	445.2	57.5	3.60	69.0
16	129.7	593.5	57.5	4.35	53.2
18	129.7	747.0	57.5	5.13	43.1
20	129.7	903.7	57.5	5.92	36.0
22					
24					
26					
28					

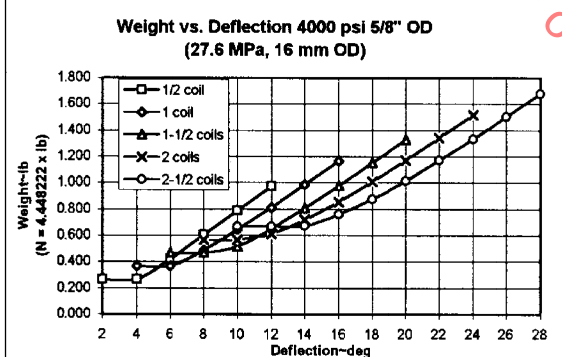
2 coils

Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2					
4					
6					
8	129.7	145.6	68.3	2.53	156.5
10	129.7	145.6	68.3	2.53	156.5
12	129.7	184.7	68.3	2.73	143.5
14	129.7	279.5	68.3	3.21	103.0
16	129.7	397.5	68.3	3.81	76.2
18	129.7	531.5	68.3	4.49	58.8
20	129.7	675.3	68.3	5.21	47.3
22	129.7	825.1	68.3	5.97	39.2
24	129.7	978.6	68.3	6.75	33.4
26					
28					

2-1/2 coils

Deflection ~ deg	A±0.8 ~mm	B±0.8 ~mm	C±0.8 ~mm	Weight ~N	Force ~N
2					
4					
6					
8					
10	129.7	145.6	79.2	2.98	147.2
12	129.7	145.6	79.2	2.98	147.2
14	129.7	146.9	79.2	2.99	170.1
16	129.7	223.8	79.2	3.38	123.5
18	129.7	325.9	79.2	3.89	90.5
20	129.7	448.6	79.2	4.52	68.5
22	129.7	584.9	79.2	5.21	53.9
24	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		





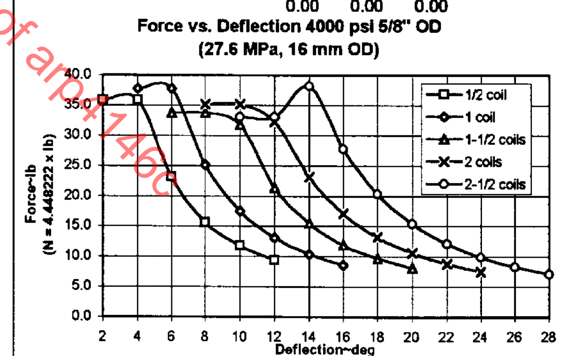


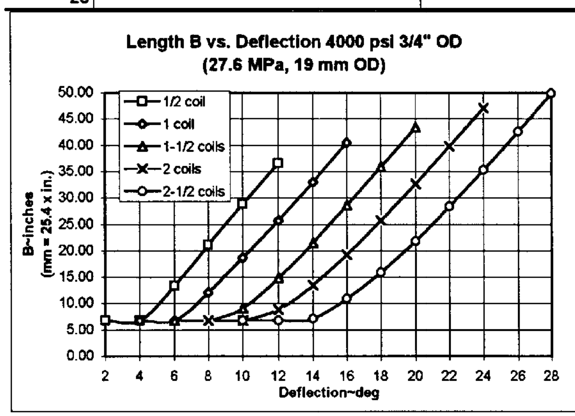
FIGURE A10 - DESIGN DATA FOR 4000 PSI - Ø5/8 IN (Ø16 MM - 27.6 MPA) STYLE A

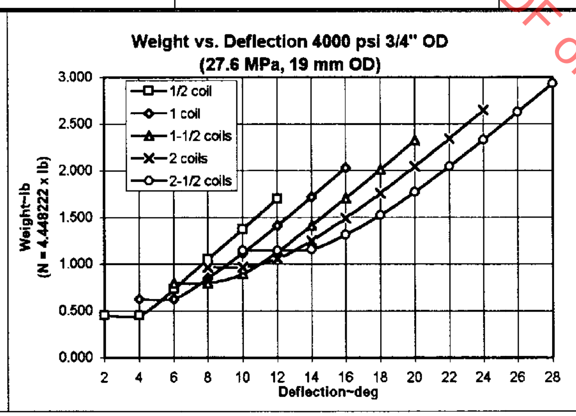
ϕ3/4" x .060 4000 psi | Rc = 5.25/5.50 in. | Pitch = 0.94±0.09 in. | D =10.50/11.01 in.

Deflection	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
~ 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	0.457	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	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
~ 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	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





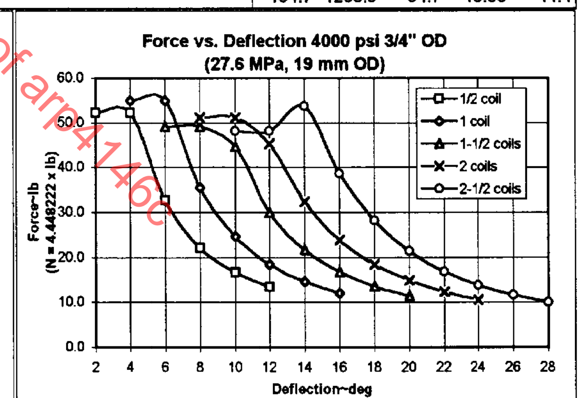


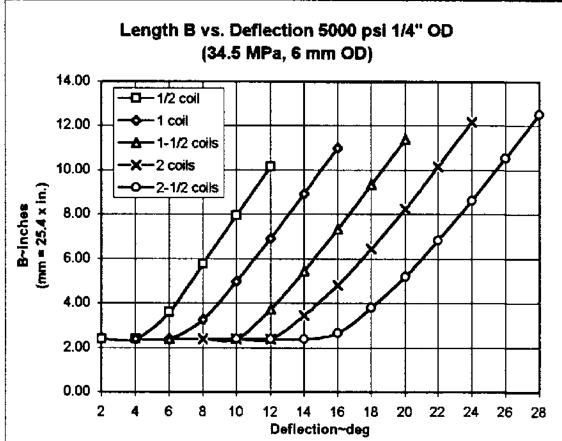
FIGURE A11 - DESIGN DATA FOR 4000 PSI - Ø3/4 IN (Ø19 MM - 27.6 MPA) STYLE A

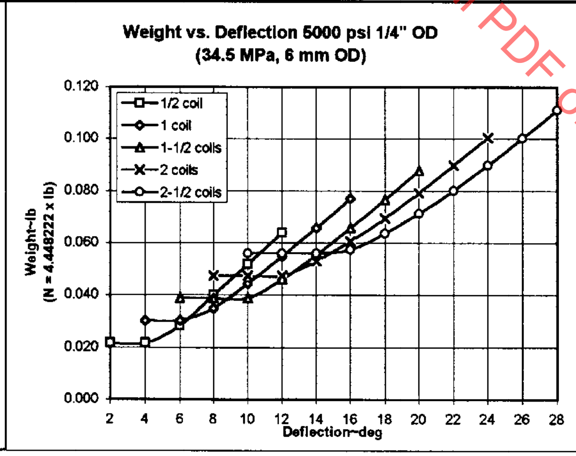
ϕ1/4" x .024 5000 psi | Rc = 2.00/2.09 in. | Pitch = 0.33±0.03 in. | D = 4.00/4.19 in.

Deflection	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
~ 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	0.022	6.3																				
4	2.15	2.40	0.00	0.022	6.3	2.15	2.40	0.75	0.030	6.8															
6	2.15	3.60	0.00	0.028	5.7	2.15	2.40	0.75	0.030	6.8	2.15	2.40	0.93	0.039	6.1										
8	2.15	5.77	0.00	0.040	3.9	2.15	3.28	0.75	0.035	6.1	2.15	2.40	0.93	0.039	6.1	2.1547	2.40	1.11	0.05	6.4					
10	2.15	7.96	0.00	0.052	2.9	2.15	5.00	0.75	0.044	4.4	2.15	2.40	0.93	0.039	7.6	2.15	2.40	1.11	0.047	6.4	2.15	2.40	1.29	0.056	6.0
12	2.15	10.15	0.00	0.064	2.3	2.15	6.91	0.75	0.055	3.3	2.15	3.73	0.93	0.046	5.5	2.1547	2.40	1.11	0.05	7.6	2.1547	2.40	1.2853	0.056	6.0
14						2.15	8.92	0.75	0.066	2.6	2.15	5.44	0.93	0.055	4.1	2.15	3.45	1.11	0.053	5.9	2.15	2.40	1.29	0.056	7.0
16						2.15	11.00	0.75	0.077	2.2	2.15	7.34	0.93	0.066	3.1	2.1547	4.83	1.11	0.06	4.5	2.1547	2.68	1.2853	0.057	7.1
18											2.15	9.34	0.93	0.077	2.5	2.1547	6.46	1.11	0.07	3.5	2.1547	3.80	1.2853	0.064	5.4
20											2.15	11.40	0.93	0.088	2.1	2.1547	8.26	1.11	0.08	2.8	2.1547	5.21	1.2853	0.071	4.2
22																2.1547	10.17	1.11	0.09	2.3	2.1547	6.84	1.2853	0.080	3.3
24																2.1547	12.16	1.11	0.10	2.0	2.1547	8.64	1.2853	0.090	2.7
26																					2.1547	10.55	1.2853	0.100	2.3
28																					2.15	12.54	1.29	0.111	1.93

ϕ6 mm x 0.61 mm 35.4 MPa | Rc = 50.8/53.1 mm | PITCH =8.4±0.8 mm | D = 101.6/106.4 mm

Deflection	1/2 coil					1 coil					1-1/2 coils					2 coils					2-1/2 coils				
~ 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	28.0																				
4	54.7	61.1	0.0	0.1	28.0	54.7	61.1	19.0	0.1	30.1															
6	54.7	91.6	0.0	0.1	25.3	54.7	61.1	19.0	0.1	30.1	54.7	61.1	23.5	0.17	27.0										
8	54.7	146.6	0.0	0.2	17.2	54.7	83.3	19.0	0.2	27.2	54.7	61.1	23.5	0.17	27.0	54.7	61.1	28.1	0.21	28.3					
10	54.7	202.1	0.0	0.2	13.0	54.7	126.9	19.0	0.2	19.4	54.7	61.1	23.5	0.17	33.7	54.7	61.1	28.1	0.21	28.3	54.7	61.1	32.6	0.25	26.6
12	54.7	257.7	0.0	0.3	10.4	54.7	175.5	19.0	0.2	14.7	54.7	94.7	23.5	0.20	24.6	54.7	61.1	28.1	0.21	34.0	54.7	61.1	32.6	0.25	26.6
14						54.7	226.7	19.0	0.3	11.7	54.7	138.2	23.5	0.25	18.1	54.7	87.7	28.1	0.24	26.2	54.7	61.1	32.6	0.25	31.1
16						54.7	279.4	19.0	0.3	9.7	54.7	186.4	23.5	0.29	14.0	54.7	122.7	28.1	0.27	20.0	54.7	68.0	32.6	0.26	31.6
18											54.7	237.1	23.5	0.34	11.3	54.7	164.0	28.1	0.31	15.6	54.7	96.6	32.6	0.28	24.2
20											54.7	289.5	23.5	0.39	9.4	54.7	209.7	28.1	0.35	12.6	54.7	132.3	32.6	0.32	18.7
22																54.7	258.4	28.1	0.40	10.4	54.7	173.8	32.6	0.36	14.8
24																54.7	309.0	28.1	0.45	8.8	54.7	219.5	32.6	0.40	12.1
26																					54.7	268.0	32.6	0.45	10.1
28																					54.7	318.5	32.6	0.49	8.6





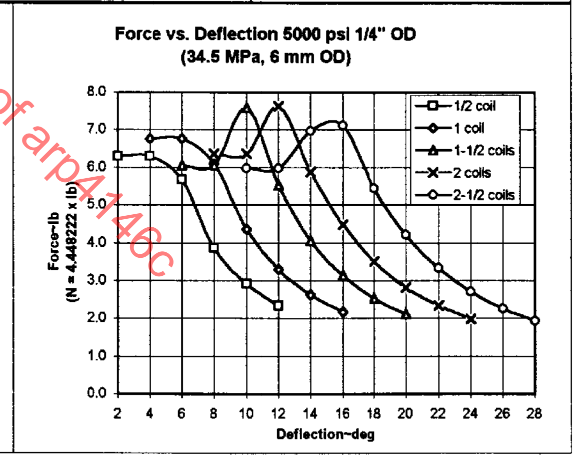


FIGURE A12 - DESIGN DATA FOR 5000 PSI - Ø1/4 IN (Ø6 MM - 34.5 MPA) STYLE A