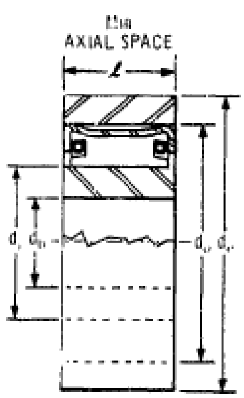
TABLE 7-3
0.375 in. PCE* SPRAG DATA



*PCE =
POSITIVE CONTINUOUS
ENGAGEMENT

No. OF SPRAGS N	INNER RACE DIA, in. d	INNER RACE BORE, in. d_B	OUTER RACE DIA, in. d_o	OUTER RACE OD, in. d_c	TORQUE CAPACITY, lb-in. 0.625 in. Min AXIAL SPACE	0.750 in. Min AXIAL SPACE	0.875 in. Min AXIAL SPACE	1.000 in. Min AXIAL SPACE
18	1.3966	0.8100	2.1433	2.6800	2,700	3,260	3,800	4,350
19	1.4931	0.8600	2.2396	2.8100	3,160	3,840	4,460	5,120
20	1.5895	0.9200	2.3361	2.9500	3,660	4,400	5,130	5,860
21	1.6860	0.9700	2.4326	3.0900	4,730	5,080	5,930	6,780
22	1.7824	1.0300	2.5290	3.2100	4,790	5,750	6,700	7,660
23	1.8739	1.0800	2.6255	3.3500	5,430	6,520	7,620	8,700
24	1.9753	1.1400	2.7219	3.4800	6,070	7,300	8,500	9,720
25	2.0718	1.1900	2.8183	3.6200	6,820	8,200	9,550	10,920
26	2.1682	1.2500	2.9147	3.7600	7,600	9,130	10,640	12,180
27	2.2647	1.3100	3.0112	3.9000	8,420	10,100	11,750	13,440
28	2.3611	1.3600	3.1076	4.0300	8,730	10,470	12,240	13,980
29	2.4576	1.4200	3.2041	4.1800	9,250	11,070	12,900	14,760
30	2.5540	1.4700	3.3005	4.3100	9,370	11,250	13,100	15,000
31	2.6505	1.5300	3.3970	4.3500	9,500	11,400	13,300	15,200
32	2.7469	1.5900	3.4934	4.5800	10,420	12,500	14,600	16,680
33	2.8435	1.6400	3.5900	4.7200	10,850	13,050	15,200	17,400
34	2.9355	1.7200	3.6820	4.8700	11,250	13,500	15,750	18,000
35	3.0275	1.7700	3.7740	5.0000	11,700	14,000	16,350	17,720
36	3.1195	1.9000	3.8660	5.2000	12,100	14,500	16,950	18,720
37	3.2115	2.1000	3.9580	5.4500	12,300	14,780	17,250	19,600
38	3.3035	2.2200	4.0500	5.6700	12,680	15,200	17,750	20,280
39	3.3955	2.3200	4.1420	5.8400	12,750	15,300	17,620	20,400
40	3.4875	2.4100	4.2340	6.0000	12,900	15,450	18,030	20,600
41	3.5795	2.5000	4.3260	6.1800	13,000	15,600	18,200	20,760
42	3.6715	2.6000	4.4180	6.3500	13,180	15,800	18,450	21,120
43	3.7635	2.7000	4.5100	6.5400	13,420	16,100	18,800	21,480
44	3.8555	2.8000	4.6020	6.7400	13,650	16,370	19,100	21,840
45	3.9475	2.9000	4.6940	6.9400	13,800	16,550	19,320	22,140
46	4.0395	3.0000	4.7860	7.1400	14,000	16,850	19,650	22,440
47	4.1322	3.1000	4.8787	7.3400	14,200	17,060	19,900	22,740
48	4.2249	3.2000	4.9714	7.5400	14,400	17,250	20,100	23,040
49	4.3176	3.3000	5.0641	7.7500	14,500	17,400	20,300	23,160
50	4.4103	3.4000	5.1566	7.9700	14,600	17,500	20,500	23,400

It is important that the gearbox designer work closely with the clutch manufacturer early in the design stage so that the overrunning function may be optimized without unnecessary compromise to either gearbox or clutch design.

7-6.1.5 Roller Clutch

Because in the past sprag clutches had been known to "roll over", some helicopter engineers selected roller clutches, which do not have the "rollover" characteristics. A roller clutch designed to transmit the same amount of torque, however, usually is heavier than the same sprag type clutch.

7-6.2 SPLINES

A spline is a machine element consisting of integral keys (spline teeth) or keyways (spaces) equally spaced around a circle or portions thereof. Splines are used principally to transmit torque from member to member. They are practically indispensable in helicopter systems, and are used in various forms on almost all rotating parts. The advantages of spline drives over other systems such as keyways and keys, serrations, pins, set-screws, and friction devices may be listed as follows:

1. No loose parts such as pins and keys required
2. High torque capacity for available space; high strength/weight ratio
3. May be self-centering

4. Given spline capacity can be upgraded by easily applied production techniques such as heat treatment, case hardening and grinding, and higher precision tooling.

5. Provides for varying axial positions when required

6. Low cost

7. Easily installed and disassembled in the field.

This paragraph describes the various types of splines and their application to helicopter systems. Applicable standards have been developed that will aid in the detail design. Reference should be made to AMCP 706-202 for detail design data.

7-6.2.1 Types of Splines

Various types of splines have been used in the past on helicopters.

The Society of Automotive Engineers (SAE) standards for involute splines have been used the most generally throughout the aircraft industry. This spline design is a variation of an involute gear tooth but having one-half the effective tooth height and using a 30-deg pressure angle. Many variations of the involute tooth spline have been used in helicopters, from the SAE tooth geometry standards to a low-pressure-angle, full-depth form. This involute spline is the most widely used of the listed types due to its ease of manufacture with standard gear cutting equipment, and the simplicity of inspection techniques. The Aerospace Gearing Committee of the American Gear Manufacturers Association (AGMA) is in the process of forming a new spline standard incorporating lower pressure angle systems that are more advantageous to the latest state-of-the-art helicopter design.

7-6.2.2 Typical Applications

Involute splines, as used in transmission systems, differ in application depending upon the types of members they join.

For involute spline joints, the various applications are:

1. Side fit spline — free floating
2. Major or minor diameter fit spline
3. Side fit spline with piloted members.

The side fit spline may be used as a self-centering type drive where angular freedom is desired and/or where radial looseness is desired to eliminate potential radial forces. Fig. 7-88 shows a free-floating drive shaft, which accommodates small misalignments between the driving and driven component.

The major or minor diameter fit spline is used where accuracy in positioning is required. This type fit may be used for mounting low-power gears or for components having moderate to high speed, where small radial offsets will not produce excessive vibrations. Fig. 7-89 is a typical installation on a moderate-speed drive shaft. A variation of the major or minor diameter fit has been used for flexible ring gear retention. Static radial clearance is provided between the gear and its housing but the major or minor diameter fit limits the radial deflection of the ring gear under load.

A side fit spline, with piloted members, is used typically for mounting a gear to a shaft. The pilots on the mating member are used to react the radial forces from the gear, allowing the spline to carry only the torque. Fig. 7-90 shows a typical gear mounting with pilot diameters. Fig. 7-91 is a curvic spline used for joining shafting with a quick-disconnect feature.

7-6.2.3 Design Considerations

In the preliminary design phase, the prime objective of the designer is to provide a geometric arrangement of a spline drive having adequate power capacity without a potential envelope redesign of the drive or the requirement for exotic manufacturing controls to maintain the required boundary limits. To attain the desired boundary limits initially, and in a simple form, the designer must formulate equations or general rules. For example, the face length-to-diameter (L/d) ratio of splines generally must be limited to insure an effective contact and bearing pattern using various types of manufacturing techniques. As a guideline, a spline length-to-diameter ratio of 2:1 or less is preferred. Where values of 1:1 are used, the basic design objective of load capacity can be achieved more readily without imposing a high degree of machining accuracy.

Most splines are critical from a wear factor (bearing stress) rather than from limit load design values caused from shear or bending. The use of maximum bearing stress allowances of the material at limit load is not a good standard for attaining satisfactory wear life. Also, there is no balance of shear capacity to wear type bearing allowables in the 30-deg pressure angle spline systems. A reduction of pressure angles, as noted by the AGMA Aerospace Spline Task Committee, will provide a better means to balance the spline geometry.

In some cases, standard gear tooth geometry (working depth $= 2.0/P_d$ where P_d is the diametral pitch, or number of teeth per inch of diameter) and moderate pressure angles of approximately 20 deg or less are more suitable spline applications in the light alloys (aluminum). The common $2.0/P_d$ working depth

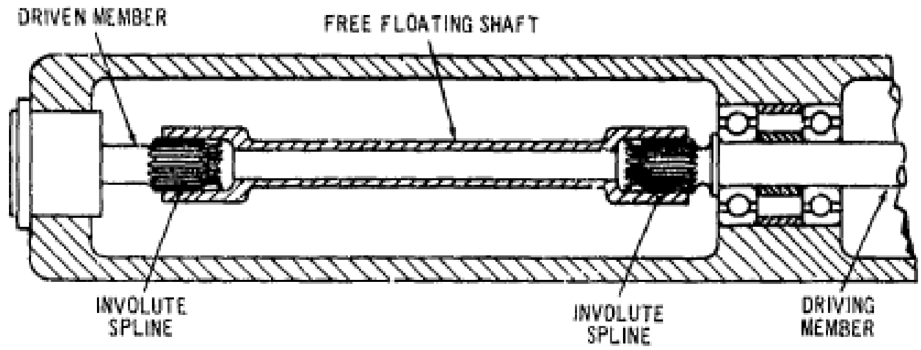


Fig. 7-88. Side Fit Spline

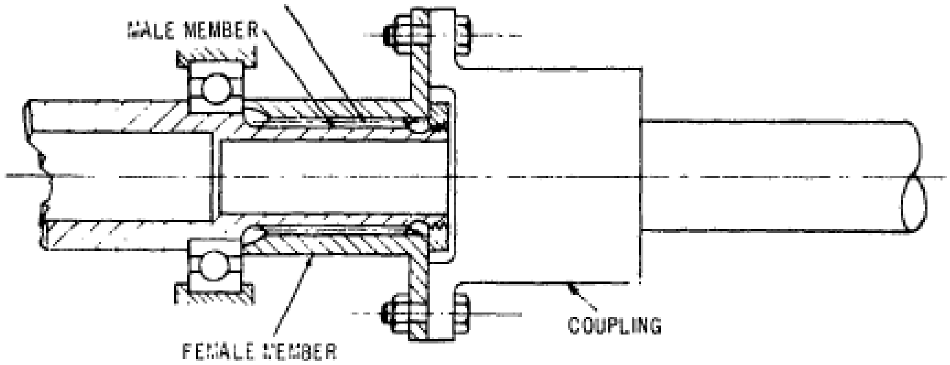


Fig. 7-89. Major or Minor Diameter Fit Spline

reduces the bearing stress by a factor of two, along with the reductions due to the lower pressure angles.

Although many variations can be presented, as a rule the designer can still use the SAE involute standards as the basic geometry in the preliminary design phase for steel-to-steel mating components. Par. 7-6.2.4 presents guidelines in establishing size of SAE splines.

7-6.2.4 Spline Capacity (SAE Type)

There are numerous allowable stresses permitted for splines, depending upon the application and method of design. For example, a clamped-up tight installation will not "work" and, therefore, will not develop readily into a fretting corrosion situation. Safe L/d ratios are dependent upon shaft section properties high enough to prevent excessive tooth end loading from torsional deflections. Accuracy of spline tooth geometry determines the percentage of total teeth capable of sharing the load. Material factors and heat treatments, together with surface finish and lubrication, also affect spline life.

In helicopter applications, most splines are highly loaded because lengths are minimized to reduce weight. These splines generally will be made from high alloy steels, with or without case carburizing and grinding to attain high tooth accuracies.

As in all helicopter applications, fatigue strength must be considered whenever stress concentrations exist. For this reason, a full or large fillet radius is required to minimize stress raisers at the highly loaded tooth root area. This requirement normally eliminates the common automotive practice of using minor diameter fits and flat root areas that require sharp radii.

High-capacity splines usually drive subsystems or large mass components at high speeds and require accurate mounting. The helicopter spline should be designed to accommodate torque only and not be subjected to additional bending stresses. For these reasons, pilot diameters should be used to provide mounting ac-

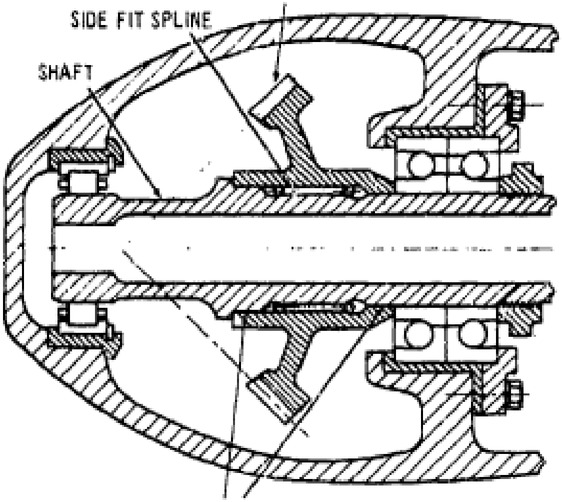


Fig. 7-90. Side Fit Spline With Piloted Members

curacy and load reaction. These diameters, usually line-to-line fits, must be square with the mounting faces to prevent axial clamp-up forces from adding bending loads to the spline teeth.

The sizing of SAE involute splines for preliminary design purposes is limited to the bearing stress values. The bearing stress value has been the limiting factor due to past experience with fretting and wear problems. The bearing stress f_{br} (psi) is a function of torque T (lb-in.) pitch diameter d, and length L (in.). These relationships are shown in Eq. 7-52.

$$f_{br} = 2T/(d^2L) \quad \text{, psi} \tag{7-52}$$

The allowable values of bearing stress F_{br} for various types of assemblies and manufacturing techniques are presented in Table 7-4. These allowable stresses are based upon maximum operating power conditions.

For steel-to-aluminum spline members, the bearing stress should not exceed values of 500 psi for loose fit and 1,000 psi for clamped-type fit.

7-6.2.5 Materials, Metallurgy, and Lubrication

The important predesign criteria for spline applications involve the required length and its effect upon component size. Shorter spline lengths are possible as allowable bearing stress F_{br} increases. Future helicopter spline loading will increase when better understanding of materials under wear conditions becomes available. Higher precision splines, with improved lubricants or dry film treatments, also will help to reduce component weight.

7-6.2.6 Failure Modes

Splines normally will fail-safe because the load is shared by a large percentage of the teeth. Exceptions have been noted when sharp fillet radii have caused stress raisers, permitting material fatigue failures. This type of failure can be serious as the fracture may open the drive train.

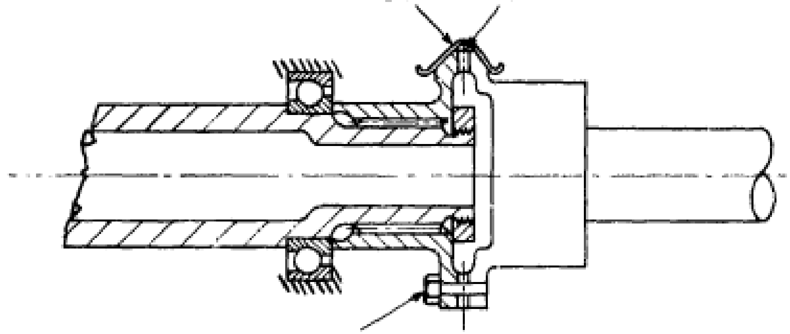


Fig. 7-91. Curvic Spline Shaft Attachment, Quick-disconnect

Failures usually cause premature component replacement, short TBOs, and excessive heat through wear and fretting corrosion. Proper lubrication and surface hardness for some applications are required to reduce wear. A clamped, nonworking spline normally will provide longer life.

7-6.3 MECHANICAL COUPLINGS

Mechanical couplings are used in all helicopters to accommodate the mismatch of drive lines, such as gearbox to shafting or shaft to shaft. The drive line mismatch is angular and axial, with the total amount being a function of installation errors, airframe deflections, and dynamic motions of the related components. Past history has shown that a large degree of attention is required in the coupling design to insure trouble-free performance.

Coupling problems occur from many causes and may result in safety-of-flight problems or excessive downtime and maintenance requirements. For example, a coupling failure on a tandem rotor synchronizing drive shaft is catastrophic. In other applications, if autorotation is successful, only an incident or forced landing results. Some failures may result only in excessive vibration, permitting a get-home capability.

Common coupling problems historically may be listed in order of importance as follows:

1. Fatigue failures, causing a disconnection in the drive train
2. Loss of lubricant or improper lubrication, causing excessive heat and welding of components, which in turn generate high force-low cycle fatigue loading into shaft end fittings
3. Improper maintenance such as shimming errors, inadequate torque on fasteners, scratches or dents in critical areas, operation beyond authorized life, too much or too little or wrong grease, and original quality control human errors.

In general, the more misalignment a coupling must accommodate, the more complex is the design. Operating and installation deflections, therefore, should be kept to a low value to insure a simple system with a minimum of friction and/or overloading. The design should minimize the requirement for care and skill during maintenance. Long-life components requiring inspection or disassembly only at long periodic intervals will prevent most in-service human errors. Corrosion becomes an important consideration in Army environments where surface protections may be lost or become inadequate to protect against pitting or stress raisers.

The aircraft environment must be considered because couplings often are located near engines and hot exhaust gases. When heat-sensitive couplings (grease-lubricated) are adjacent to engines, heat insulators or cooling provisions may be required for protection from conduction and radiation of engine heat. Seals and other surfaces must be insensitive to exhaust gases.

There are four basic coupling types presently used on helicopter drive systems:

1. Laminated ring flexures
2. Flexible disks
3. Crowned gear coupling
4. Universal joints.

A fifth, the elastomeric type, may become significant if the present R&D programs are successful. The types most commonly used are shown in Figs. 7-92, 7-93, and 7-94. All these types effectively will relieve cyclic bending load at shaft ends caused by misalignments. Each coupling has certain advantages over others depending upon the application requirements. Each type of coupling is discussed in the paragraphs that follow.

TABLE 7-4
ALLOWABLE STRESS FOR STEEL SPLINES WITH VARIOUS MOUNTING AND TOOTH PARAMETERS

	ALLOWABLE BEARING STRESS F_{br}, psi		
ASSEMBLY	AS MACHINED NO LUBRICATION	GROUND	HARDENED AND GROUND
LOOSE FIT (FLOATING)	5,000	7,500	15,000
CLAMPED FIT	7,500	10,000	20,000

IN SOME APPLICATIONS PAST EXPERIENCE HAS SHOWN THAT HIGHER ALLOWABLES MAY BE USED DEPENDING ON

1. LOW L/D RATIOS
2. LUBRICATION
3. MATERIALS
4. DEGREE OF PRECISION

ALSO, IN SOME APPLICATIONS, PAST EXPERIENCE HAS SHOWN LOWER ALLOWABLES MUST BE USED DEPENDING ON

1. HIGH L/D RATIOS
2. EXCESSIVE FLEXURAL MOVEMENT OF SPLINE MEMBERS
3. POOR GEOMETRY

INVOLUTE SPLINES

Involute splines are used to transfer torque between shafts and flanges, gears and shafts, and shaft and shafts. The design of splines is well covered by publications of such organizations as the American Gear Manufacturers Association and the Society of Automotive Engineerings. The most common problem associated with splines is wear due to fretting, particularly with loose splines such as those used on quill shafts. Attention to the following details can significantly lessen the chance of encountering spline problems. The most important consideration in the design of splines is strict observance of the limits on allowable bearing stress. With tight splines care should be taken to provide an adequate length pilot to react any type of bending loads. Avoid the use of pilots which are too short. With loose splines lubrication is a vital factor in determining how well the spline will perform. It is desirable, if possible, to keep the spline area flooded with oil at all times. Oil dams such as that shown in Figure 17 can be used to accomplish this. Crowning of loose splines is also necessary to prevent excessive wear. The amount of the crown should be carefully calculated on the basis of tolerances and full load deflections.

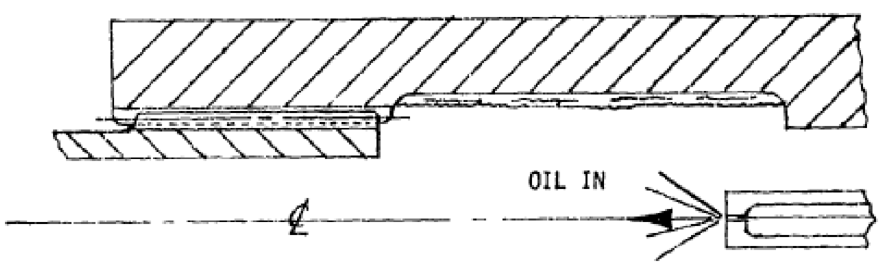
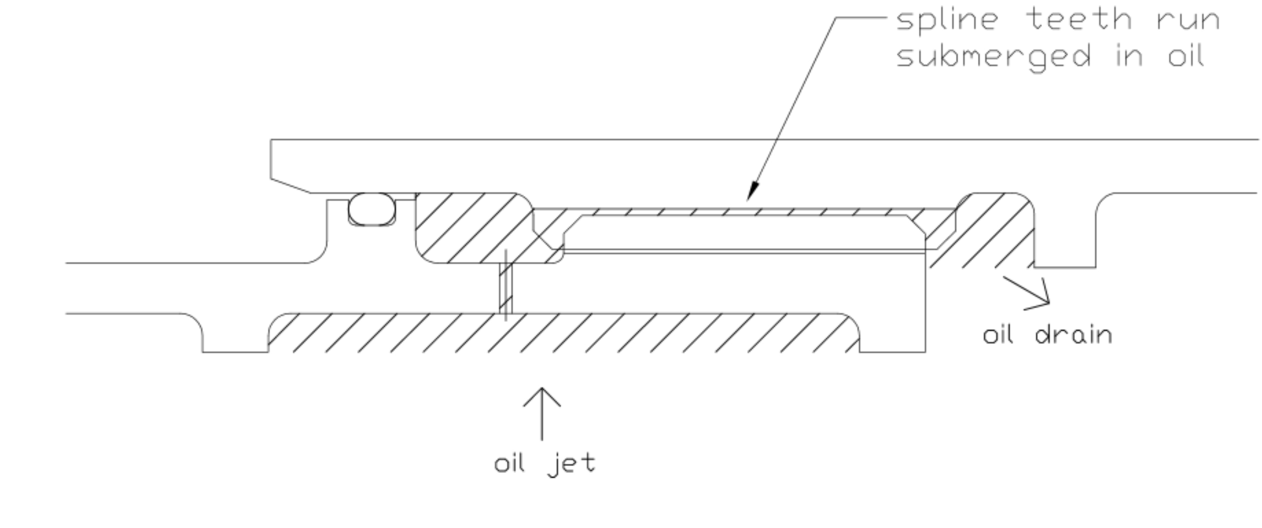


Figure 17. OIL DAM FOR LUBRICATION OF LOOSE SPLINES


spline teeth run
submerged in oil
oil drain
oil jet