HYDRAULIC REMOVAL OF COUPLING HUBS—KEYED AND KEYLESS

by

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ABSTRACT

In rotating machinery, torque is transmitted from shafts to coupling hubs (or vice versa) through keys, friction, or a combination of the two. As a rule, coupling hubs must be installed on shafts with a certain amount of interference. This interference has two purposes: to prevent rocking of the hub on the shaft, and to help in the torque transmission. With sufficient interference all the torque can be transmitted by friction, and keys can be eliminated.

Interference has two disadvantages: it makes installation difficult, and hub removal even more difficult. Hydraulic methods of hub removal are discussed. These methods are sound, make for easy and quick hub removal, and are safe.

Some engineers are reluctant to use hydraulic removal for two reasons: it requires specialized tools and better training of mechanics, and it was known to be potentially dangerous. As any new and sophisticated procedure, it also received a bad name from early failures, all caused by misuse.

The following topics are discussed:

- Torque transmission through keys
- Installation of keyed hubs using interference
- Torque transmission through friction
- Installation of keyless hubs, heat-assisted installation, hydraulic assisted installation
- Hydraulic removal of hubs, dismounting keyed hubs, dismounting keyless hubs
- Failure cases

Hydraulic methods for hub removal were discussed in previous papers [1, 2]. The purpose herein is to compile and update previous information, and to describe good practices.

TORQUE TRANSMISSION THROUGH KEYS

Keys are such an old machine part that the authors could not trace their origin. There are many shapes of keys, and all are standardized. Ultimately, all keys transmit torque through shearing of a rectangular cross section. Three completely different shapes of keys are shown in Figure 1, all having the same shearing section: a rectangle of width, W, and a length, L_k.

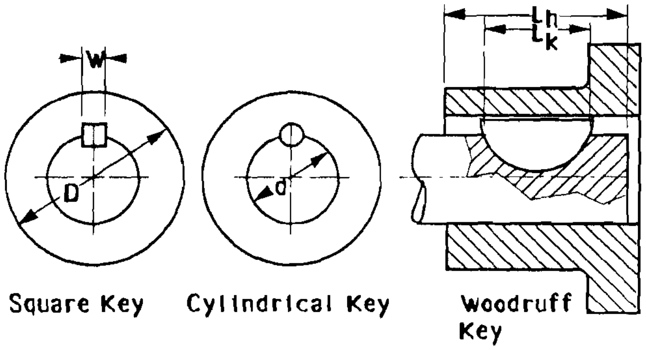

Figure 1. Three Types of Shaft Keys. Note: The basic dimensions (width and length) remain the same for all types.

Key dimensions were standardized about 150 years ago: the width to be 1/4 of shaft diameter, and the length to be 1.5 times shaft diameter. A simple shear stress calculation will demonstrate why these particular dimensions were chosen.

The shear stress generated by torque in a cylindrical shaft is:

$$\tau_s = \frac{2 \bullet T}{\pi \bullet r^3} = \frac{5.3 \times T}{d^3}$$

where
d = shaft diameter
T = torque
Note: if d is in in, and T in in/lb, τ is lb/in².

The shear stress generated by torque in the rectangular cross section of the key is:

$$\tau_k = \frac{2 \bullet T}{d \bullet W \bullet L_k}$$

Introducing the standardized key dimensions (W = d/4 and L = 1.5 d) the following is obtained:

$$\tau_k = \frac{5.1 \times T}{d^3}$$

It can be seen that the shear stresses in the shaft and in the key are practically identical; it goes without saying that the strength of the two materials must also be the same. Amazingly, this simple rule was forgotten over the years; today, almost all engineering handbooks include table after table of various key dimensions, but not a word about key material.

The authors have seen a number of costly machine failures that were caused by the use of low carbon steel keys in applications were both shafts and hubs were made of heat-treated alloy steels. An important rule to remember is that *the key material, and the key hardness, should be similar to that of the shaft or hub.*

INSTALLATION OF KEYED HUBS USING INTERFERENCE

All couplings resist being misaligned; misalignment causes all types of couplings to tend to rock on their shafts. The back-and-forth motions of small amplitude and high frequency cause fretting wear to occur on bore and shaft surfaces; fretting induces fatigue in shafts, with catastrophic consequences, as shown in Figure 2.

Figure 2. Fretting-Induced Shaft Failure. Note: Fretting was caused by the rocking of the hub on its shaft, motion possible because of installation without sufficient interference.

The only way to avoid fretting is to use interference at installation. Interference is created when the bore diameter is slightly smaller that the shaft diameter. How much interference is required for preventing fretting occurrence? First define interference:

Interference is the difference between the bore and shaft diameters, divided by the shaft diameter. Therefore, interference is dimensionless: it is customary to refer to it as in/in, or mm/mm.

Example A:

A cylindrical shaft has a diameter of 4.000 in, and its hub bore has a diameter of 3.996 in. The resulting interference is.

$$i = \frac{4.000 - 3.996}{4.000} = 0.001$$

Example B:

A tapered shaft has a nominal diameter of 3.000 in, and a taper of 3/4 in/ft. The hub bore large end has a diameter of 2.995 in. At installation, the hub is advanced (drawn) on the shaft 0.048 in. The resulting interference is:

$$i = \frac{\text{taper} \times \text{advance}}{\text{shaft diameter}} = \frac{0.75}{12} \times 0.048 \times \frac{1}{3.000} = 0.001$$

Note that the bore diameter does not enter in the calculations; however, it must be smaller than the shaft by at least:

$$i \times d = 0.001 \times 3.000 = 0.003 \text{ in}$$

Going back to the question of how much interference is required to prevent fretting: experience has shown that a minimum of 0.0005 (in per in) at operating conditions will prevent the occurrence of fretting. Rotating speed creates centrifugal acceleration, which in turn causes the hub bore to grow. To ensure the minimum interference at operating speed, the authors recommend that:

- At speeds up to 3,600 rpm the mounting interference should be 0.00075,
- at speeds between 3,600 and 8,000 rpm the mounting interference should be 0.001, and
- at speeds above 8,000 rpm the coupling or machine manufacturer should be consulted, as the amount of interference also becomes a function of the type and diameter of couplings.

TORQUE TRANSMISSION THROUGH FRICTION

Interference creates a contact pressure at the hub-to-shaft interface, and this pressure, combined with friction, helps in the transmission of torque. The torque that can be transmitted by friction can be calculated using the formula:

$$T = k \times 10^6 \times d^2 \times (1 - c^2) \times L_h \times i$$

where:
d = shaft nominal diameter
D = hub outside diameter
L_h = hub effective length
i = interference
c = ~~D/d~~ = d/D

Note: If all the dimensions are in inches (in), T is in in/lb, and k = 2.8 lb/in^3

Two assumptions were made: that the hub and shaft are made of steel, and that the friction coefficient is 0.12 (note: torque is directly proportional to the friction coefficient). For details about this formula see Calistrat [1].

The effective hub length is the length of contact between the hub and shaft; it determines the area of contact between the two. The area lost through keyways or O-ring grooves should be discounted, as it is compensated by a proportional increase in contact pressure.

Example C:

Using the data from *Example B*, and assuming an effective hub length of 4.0 in and a hub outside diameter of 4.5 in, the following is obtained:

$$T = 2.8 \times 10^6 \times 3^2 \times \left(1 - \left(\frac{3}{4.5}\right)^2\right) \times 4.5 \times 0.001 = 62{,}940 \text{ in}\bullet\text{lbs}$$

Interestingly, this is about the rated torque of a general-purpose gear-type coupling for a 3.0 in shaft. Although all the torque of the shaft could be transmitted through friction, no margin exists for torque fluctuations, and particularly for peak torques. The above example shows that, *during normal operating conditions*, a 0.001 interference relieves most of the stresses in keys used in general-purpose couplings.

INFLUENCE OF SPEED ON INTERFERENCE

Mounting interference is reduced by the hubs is centrifugal growth. At speed, the actual interference is:

$$i_s = i - 0.055 \bullet \text{rpm}^2 \bullet D^2 \bullet 10^{-12}$$

This formula shows that the reduction in mounting interference is greatly influenced by the hub's outside diameter, and by the rotating speed. For hubs with large flanges, such as the one shown in Figure 1, the actual interference is not uniform across the hub length; it is smallest just under the flange.

Example D:

A flanged coupling hub is installed on a 3.5 in shaft, rotating at 6,000 rpm. The outside diameter of the hub body is 5.5 in, and the flange outside diameter is 8.0 in. The mounting interference is 0.00075 (in/in).

The actual interference, at operating speed, varies as follows:

Under the flange

$$i_s = 0.00075 - 0.055 \times 6000^2 \times 5.5^2 \times 10^{-12} = 0.00069$$
or 92 percent of mounting

Under the hub

$$i_s = 0.00075 - 0.055 \times 6000^2 \times 8^2 \times 10^{-12} = 0.00062$$
or 83 percent of mounting

Average interference, to be used in the calculation of torque transmission ability:

$$i_s = (0.00069 + 0.00062)/2 = 0.00065$$
or 87 percent mounting

INSTALLATION OF KEYLESS HUBS

Without keys, all the torque (including momentary peak torques) must be transmitted through friction between the hub bore and shaft. The friction generated by a 0.001 interference can transmit most of the general-purpose coupling torques. However, keyless hubs are mostly (but not exclusively) used with special-purpose couplings, which are made of alloy steels, operate at high speeds, and can transmit larger torques than general-purpose couplings.

Therefore, in keyless couplings the effective interference must be much larger. It is customary to use 0.002 to 0.0025 (in/in) interference. All the formulae previously given apply.

Keyless hubs are used almost exclusively on tapered shafts.

Manufacturers seldom give recommendations on how much interference should be used with their keyed-hub couplings; they always give detailed instructions in the case of keyless hubs. One particular reason to follow manufacturers instructions is the fact that interference causes high stresses in hubs. A 0.003 interference will create stresses as high as the yield strength of alloyed, heat treated steels. Therefore, such a high interference should not be used. However, even a lower interference could create problems in hubs with a thin shell, or hubs that have oil injection holes drilled in their bodies. In such cases stresses can be very high, and the coupling manufacturer instructions must be closely followed.

The authors know of one case where a replacement hub was made by an independent machine shop, of incorrect material. The hub split open at installation, which was fortunate; it could have failed after the machine was started!

There are two ways to install keyless hubs: through heat expansion, or through hydraulic expansion.

Heat-Assisted Installation

The biggest advantage of heat installation is that the resulting friction coefficient is larger than when oil dilation is used. Experiments have shown that the dry friction coefficient can be as high as 0.20, as compared with 0.12 in the case of hydraulic installation. Therefore, either a larger torque can be transmitted, or a smaller interference can be used. On the other hand, heat expansion precludes the use of seals at the hub-to-shaft interface, and requires an oven onsite.

Thermal expansion calculations show that for every 0.001 interference about 160°F difference between the hub and shaft is required. Therefore, for a 0.0025 interference, and a shaft at 80°F, the minimum hub temperature must be 500°F. If a margin for errors is provided, hubs must be heated close to steel tempering temperatures, which could cause degradation of material strength.

The lack of seals can cause two problems at removal: first, sufficient pressure for dilation might not be achieved; second, scoring of the shaft and bore might occur. The deformation of a sealless hub under pressure is shown in Figure 3. It is evident that in order to seal the oil, a high contact pressure must exist at the bore edges. Rounded corners are used in order to minimize the possibility of scoring.

The following steps should be followed for the hub installation:

☐ *Clean contact surfaces* of shafts and couplings very carefully. If rubbing is required to remove preservatives, use a nonabrasive material, and do not use axial motions. Some coupling manufacturers use a dry preservative that can be removed only through lapping. It is very important to remove all preservatives, because if left on, they will significantly reduce the friction coefficient.

☐ *Measure the shaft and the bore* and ensure that the dimensions are as specified by the manufacturer. Tapered surfaces should be checked with tapered gauges; cylindrical surfaces should be checked with micrometers.

☐ *Check for proper contact* (for tapered shafts only). After the shaft and hub bore are thoroughly cleaned, spread a thin layer of mechanic's blue on the shaft and push the hub snugly. While applying a light axial pressure, rotate the coupling hub a small amount, and back up to the original position. Carefully remove the hub and check the bore for contact, by the amount of colored area. At least 80 percent, and preferably 90 percent of the bore should show contact.

☐ *Find the problem.* If less than 80 percent contact is found, check the accuracy of the surfaces using tapered gauges. It is important to find the problem before corrective measures are taken.

☐ *Improve the contact.* If problems are found, either the shaft, the bore, or both, must be corrected through lapping. The following rules should be followed:

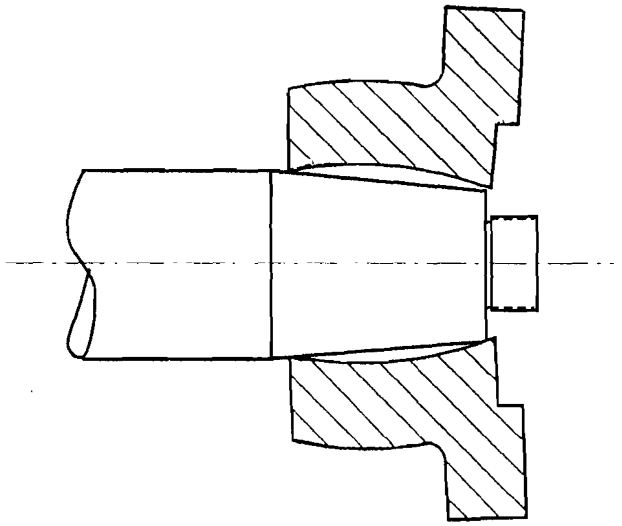

Figure 3. Hub Dilation with Hydraulic Pressure. Note: The barrel-type distortion is typical of sealless hubs.

- Hubs are more often at fault for lack of contact than shafts. If serious defects are found it is advisable to first send the problem hub to a grinding shop to be "sparked out." A minimum amount of material should be removed to reestablish good contact.

- Use a ring and plug lapping tool set; never lap a hub on its shaft. Lapping tools are made of soft materials, usually cast iron. Using hard tools (such as gauges) will reduce the effectiveness of lapping, and the tools might become damaged quickly.

- Lapping will change the hub axial position on the shaft. As a general rule, hubs move axially 30 times more than the thickness removed through lapping. For example, if one mill (0.001 in) is removed, the hub standoff will be reduced by 0.030 in. Excessive lapping might require machine realignment, of use of shims in metal flexible element couplings.

- To expedite the lapping process, start with a coarse compound, and change to a progressively finer grit as the defects are corrected.

☐ *Clean the lapped surfaces.* Remove all traces of lapping compound, using a solvent and lint-free towels. Recheck the hub-to-shaft contact.

☐ *Protect surfaces*, by spreading thin oil on the shaft and hub bore (to prevent rusting).

☐ *Measure the hub draw* (advance).

- Using a depth micrometer, measure from the face of the hub to the end of the shaft, and record the "start" reading. A second reading should be taken, if possible, either from a fixed point on the machine, or from a split collar attached on the shaft, behind the hub. Use parallel bars, snap gauges, or feeler gauges, as required.

- Calculate the hub overhang after installation, by subtracting the intended draw from the "start" dimension. It is possible that a negative value may be obtained, meaning that the shaft will protrude out of the hub. Although an undesirable condition, it is often encountered in cases where many corrections were made for proper contact. If the shaft protrudes, a special retaining nut, incorporating a counterbore, must be made.

☐ *Clean surfaces.* Just before installation clean the shaft and the bore of all lubricants, using a solvent and, if necessary, a lint-free cloth.

☐ *Heat the hub* to the recommended temperature. Use an air oven or induction heater. If the temperature to which the hub must be heated is not specified, use the following rule: 160°F *difference* between hub and shaft, for every 0.001 in/in interference, to which an additional number of degrees should be added as a safety margin.

☐ *Remove the hub* from the oven and place it quickly on the shaft. A positive stop must be provided in front of, or behind the hub, otherwise the advance could be wrong.

☐ *Measure again* the hub draw (advance). The hub must be advanced on the shaft exactly the amount specified. Too little advance could result in the hub spinning on the shaft; too much advance could result in the hub splitting at or shortly after installation.

Hydraulic-Assisted Installation

Hubs with tapered bores can also be expanded hydraulically. The advance (draw) can be either mechanical, using a special shaft nut, or hydraulic, using an annular cylinder (hydraulic nut). The arrangement is shown in Figure 4.

Hydraulic advance has two advantages over the mechanical advance: it does nor require a tool to prevent the shaft from rotating, and the hydraulic nut can also be used at removal.

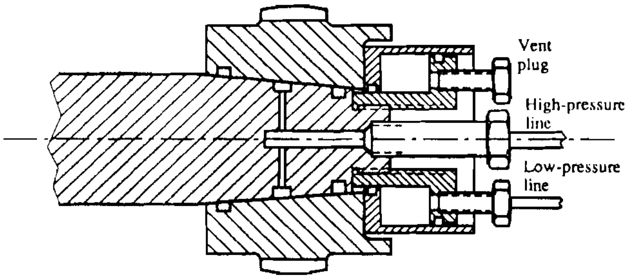

Figure 4. Installation/Removal Hydraulic Tool. Note: This tool allows for heat-less installation, and for safe removal.

The required pressure for expanding the bore is high, usually between 20,000 and 35,000 psi.

Three special tools are needed for hydraulic advance: an installation tool (hydraulic nut), a high-pressure (50,000 psi) oil pump with pressure gauge, and a low-pressure (10,000 psi) oil pump with pressure gauge.

To ensure a successful installation, the following procedure is recommended:

☐ *Clean contact surfaces* of shaft and coupling very carefully. If rubbing is required to remove preservatives, use a nonabrasive material, and do not use axial motions. Some coupling manufacturers use a dry preservative that can be removed only through lapping. Removing all preservatives is very important, because if left on, they will significantly reduce the friction coefficient.

☐ *Measure the shaft and the bore* and ensure that the dimensions are as specified by the manufacturer. Tapered surfaces should be checked with tapered gages.

☐ *Check for burs on shaft ends,* O-ring grooves and oil inlet passages. Sharp edges can nick the seals and cause difficulties at removal. Check coupling bore for similar conditions. Burs and drag marks can be removed using a fine "Indian" grade hone. Never hone axially.

☐ *Check for proper contact.* After the shaft and hub bore are thoroughly cleaned, spread a thin layer of mechanic's blue on the shaft and push the hub snugly. While applying a light axial pressure, slightly rotate the coupling hub, and back up to the original position. Carefully remove the hub and check the bore for contact, by the amount of colored area. At least 80 percent, and preferably 90 percent, of the bore should show contact.

☐ *Find the problem.* If less than 80 percent contact is found, check the accuracy of the surfaces using tapered gauges. It is important to find the problem before corrective measures are taken.

☐ *Improve the contact.* If problems are found, either the shaft, the bore, or both, must be corrected through lapping. The following rules should be followed:

- Hubs are more often at fault for lack of contact than shafts. If serious defects are found it is advisable to first send the problem hub to a grinding shop to be "sparked out." A minimum amount of material should be removed to reestablish good contact.
- Use a ring and plug lapping tool set; never lap a hub on its shaft. Lapping tools are made of soft materials, usually cast iron. Using hard tools (such as gauges) will reduce the effectiveness of lapping, and the tools might become damaged quickly.
- Lapping will change the hub axial position on the shaft. As a general rule, the hub moves axially 30 times more than the thickness removed through lapping. For example, if one mill (0.001 in) is removed, the hub standoff will be reduced by 0.030 in. Excessive lapping might require machine realignment, or use of shims in metal flexible element couplings.
- To expedite the lapping process, start with a coarse compound, and change to a progressively finer grit as the defects are corrected.

☐ *Clean the lapped surfaces.* Remove all traces of lapping compound, using a solvent and lint-free towels. Recheck the hub-to-shaft contact.

☐ *Protect the surfaces,* by spreading thin oil on the shaft and hub bore (to prevent rusting).

☐ *Measure the hub draw* (advance).

- Without any O-rings or backup rings, install the hub snugly on the shaft. This is the start position.
- Using a depth micrometer, measure from the face of the hub to the end of the shaft, and record the "start" reading. A second reading should be taken, if possible, either from a fixed point on the machine, or from a split collar attached on the shaft, behind the hub. Use parallel bars, snap gauges, or feeler gauges, as required.
- Obtain the hub overhung after installation, by subtracting the intended draw from the "start" dimension. It is possible that a negative value will be obtained, meaning that the shaft will protrude out of the hub. Although an undesirable condition, it is often encountered in cases where many corrections were made for proper contact. If the shaft protrudes, a special retaining nut, incorporating a counterbore, must be made.

☐ *Check if proper O-rings and backup rings are available.* The combination should fit in the groove without too much effort. O-rings will protrude slightly out of the groove. Backup rings are available as either nonsplit hard rubber, or split white nylon. The split rings must be individually adjusted to fit their grooves, by cutting off some material. Neither overlapping, nor gaps are acceptable. Back-up rings should not protrude out of the grooves.

☐ *Install O-rings and backup rings* in shaft and hub grooves. Oil is pumped between the hub and shaft through a shallow circular groove machined either in the hub or in the shaft. Install the O-rings toward this groove, the backup rings away from this groove. After they are installed, look again! The O-rings must be between the backup rings and the oil grooves! Spread a little bit of hydraulic oil on all rubber surfaces.

☐ *Mount "other" components.* Read the coupling installation procedure again. Must other components (such as a sleeve) be mounted on the shaft before the hub? If so, now is the time to do it.

☐ *Apply a thin layer of hydraulic oil on the shaft.* This oil will prevent the rolling or twisting of the seals. The high pressures used during removal will not be contained by defective seals.

☐ *Mount the hub on the shaft.* Avoid pining the O-rings during mounting. The o-rings, being taller than the grooves in which they are installed, will prevent the hub from advancing to the "start" position. This is normal.

☐ *Mount the installation tool.* Wet the threads with thin oil, and rotate the tool until it butts against the shaft shoulder. The last few turns will require the use of a spanner wrench.

☐ *Connect the hydraulic lines.* Connect the *collapsed* installation tool to the low-pressure oil pump (5,000 psi minimum). Connect the high-pressure oil pump (40,000 psi minimum) to the hole provided either in the center of the shaft or on the outside diameter of the hub, depending on design. Loosen the vent plug of the installation tool and pump all the air out; retighten the plug. Both pumps must be equipped with pressure gauges.

Note: Use only hydraulic oil in the high-pressure pump. The use of lubricating oils could cause the installed hub to slide off the shaft.

☐ *Advance the hub* to the start position by pumping the low-pressure oil pump. Continue pumping until the hub advances 0.005 to 0.010 in beyond the start position.

☐ *Expand the hub.* Pump the high-pressure pump until the gauge reads between 15,000 and 17,000 psi. As the pressure increases, the hub will tend to move off the shaft. Correct this movement by occasionally increasing the pressure at the installation tool.

☐ *Check for oil leaks.* The pressure at the high-pressure oil pump will drop rapidly at first because the air in the system escapes past the O-rings. Continue pumping until the pressure stabilizes. The hub should not be advanced on the shaft if leaks are observed! A maximum pressure loss of 1,000 psi/minute is acceptable. If the pressure drops faster than that, remove the hub and replace the O-rings. However, before removing the hub, make sure that the leaks do not occur at the hydraulic connections.

☐ *Advance the hub.* Increase the pressure at the installation tool and the hub will advance on the shaft. If all the previous steps were observed, the pressure at the high-pressure gauge will gradually increase (by itself!) as the hub advances. If the pressure does not increase, then stop! Remove the hub and check the o-rings. If the pressure increases, keep advancing the hub until it touches the split collar or until the specified advance is reached. Do not allow the pressure to exceed 30,000 psi. If it does, open the pump's valve slowly and release some oil. If in doing this, the pressure drops below 25,000 psi, pump the high pressure pump to 25,000 psi, and continue the hub advance.

☐ *Seat the hub.* After ensuring that the hub is in the desired position, slowly release all the pressure at the high-pressure pump only. The oil present in the space between hub and shaft must be given time to return to the pump, less the hub slides off. Therefore, do not work on that hub for about one-half hour, or one hour in cold weather. After this waiting period, release all the pressure at the installation tool and remove it from the shaft.

☐ *Verify the advance.* Measure and then record the new overhang of the hub over the shaft. Subtract from the overhang measured in the "start" position, and the result must be the same as the specified advance, within the given tolerances. Record the actual advance for future reference.

☐ *Secure the hub.* Remove the split collar from the shaft and install the retaining nut, but do not overtighten. Secure the nut with the setscrews provided. Note: set screws should have a "cup" point, and the point should imbed in the shaft surface, not in the hub face. If the nut is secured to the hub, and the hub spins on the shaft, the nut could become loose and actually fall off the shaft.

HYDRAULIC REMOVAL OF HUBS

Dismounting Keyed Hubs

Hubs that have been installed for a long time have a tendency to stick to their shafts. This sticking, in addition to the friction forces generated by interference, makes for difficult removal.

To help in the removal of keyed hubs, it is recommended to smear the shaft, at installation, with an antiseizing compound. Many such compounds are commercially available. The authors recommend the use of compounds blended with chromium oxides, which are easy to recognize by their silvery-gray color. An economical alternative is the use of greases containing zinc oxides, which are white-gray in color. The use of antiseizing compounds reduces by a small extent the friction coefficient, and slightly less torque can be transmitted through friction. Antiseizing compounds are a mixture of solids (such as chromium oxide powder) and greases. At the moment a hot hub is installed on a shaft, all the oil from the compound is eliminated, and only the solids remain. Therefore, the friction coefficient is reduced, but only by a small amount.

There are many mechanical methods available for hub removal; however, only hub removal methods that use hydraulic pressure for the dilation of the hub are discussed here. The advantages of hydraulic removal are: on one hand, dilation reduces the mounting interference, and on the other hand the grease (or hydraulic oil) lubricates the mating surfaces. Use of the hydraulic removal method greatly simplifies hub removal, and completely eliminates the use of open flames on coupling components.

Hydraulic removal requires a slight modification of the existing hubs, but the cost of such modifications are probably recovered by the downtime saved at the first use.

Two methods are available, one which uses a plain grease gun [3], and another that uses two oil pumps [2].

Two hubs are shown in Figure 5 modified for removal using a grease gun. Automotive-type guns can deliver a pressure of about 10,000 psi. Considering that 0.001 interference creates a contact pressure of 8,300 psi (for D/d = 1.5), grease guns can easily overcome the contact pressure generated by interference.

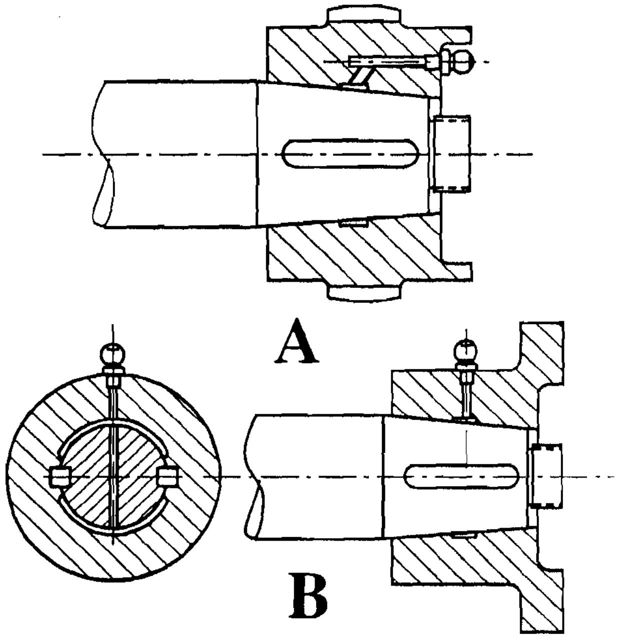

Figure 5. Hydraulic (Grease) Removal Methods for Keyed Hubs. Note: Method A applies to geared hubs; method B applies to flanged hubs for all types of couplings.

The groove that distributes grease around the bore must be machined so that it does not break into the keyway. There are two ways to machine such a groove: either through milling, or by offset installation of the hub in a lathe's chuck. Either way, a minimum of 1/4 in should exist between the end of the groove and the keyway. Two independent grooves must be machined for hubs with two keyways.

Connecting the grooves to the outside of a gear-coupling hub requires more skill than in the case of flanged hubs. In either case, a small grease fitting is installed at the outside of the hub. This grease fitting can be left in place during coupling operation, unless it interferes with other coupling components. For hubs with two keyways hubs must either have two grease fittings (and two grease guns must be used at removal), or the two grooves can be connected by a small (1/8 in) hole drilled through the shaft, perpendicular to the plane of the keyways (Figure 5).

To remove a hub so equipped, simply pump grease in the hub while a pulling force is applied. For tapered hubs, it is possible that no pulling force is needed; actually, it is safe to keep the shaft nut in place (but slightly loose) during removal. For cylindrical bores, the best tool to use is one similar to the automotive steering-wheel puller, attached with high-strength bolts to the puller holes of the hub. An air impact wrench will ensure continuous movement of the hub while hydraulic pressure is maintained.

The oil injection method is discussed by Munyon and Zilberman [2], and is illustrated in Figure 6. It is basically the same as the grease-gun method, except it uses two oil pumps, one for dilating the hub, the other for an oil ram. The authors believe that the use of a steering wheel puller is as efficient, but simpler.

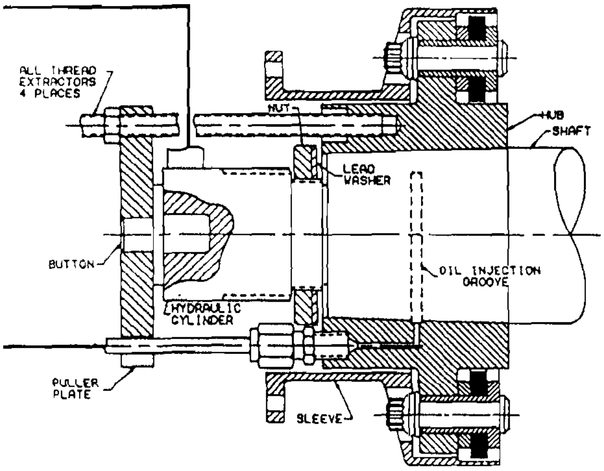

Figure 6. Hydraulic (Oil) Removal Methods for Keyed Hubs. Note: The hydraulic ram can be replaced with a steering-wheel-type mechanical puller.

Dismounting Keyless Hubs

It is important to recognize that hydraulically removing a hub involves some danger, and safety precautions must be carefully observed. Because hubs are expanded at installation, they store a substantial amount of potential energy, just like a stretched spring. When a hub is removed, this potential energy is abruptly released and transformed into kinetic energy, i.e., the hub is accelerated axially. Pumping oil between the hub and shaft provides the lubricant on which the hub slides.

Another force that helps in removing hubs is the diametral difference between the two ends of the bore (or between the two O-rings), which creates an annular hydraulic piston.

Example: E:

A 4.0 in shaft with 3/4 in/ft taper and a three-in axial distance between o-rings becomes an annular piston with an area of 1.2 in^2. If the hydraulic pressure is 25,000 psi, the resultant axial force is 15 tons.

It is obvious that hubs must be stopped, or they will fly off the shaft and damage themselves and anything they encounter. One method for stopping a hub is illustrated in Figure 7. The retaining nut is backed off sufficiently to allow the hub to move slightly more than the distance it was advanced at installation. Two steps should be taken to safely dissipate the kinetic energy:

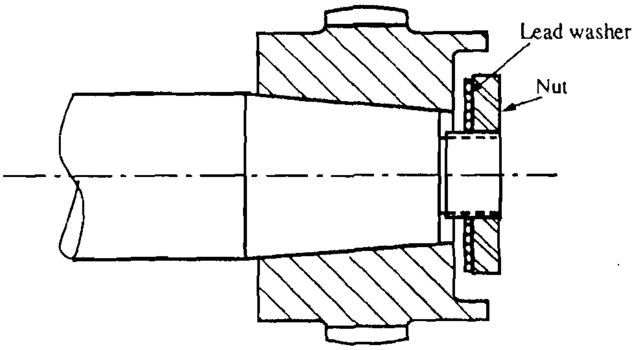

Figure 7. Mechanical Stop for Hydraulic Hub Removal. Note: The distortion of a lead ring absorbs the kinetic energy of hubs.

First, a lead washer (minimum 1/8 in thick) should be installed between the hub and the nut.

Second, the gap should be made only 0.010 in to 0.020 in wider than the original advance. A larger gap will allow the hub to attain a too-high velocity. The lead washer will absorb the energy through deformation. The authors know of one case where, without a lead washer and with a wide gap, the threaded portion of the shaft was snapped off!

Even with all these precautions, personnel should never stand in line with the shaft when hubs are being removed.

After a stop is provided, hydraulic pressure should be applied slowly. A too-quick increase in pressure will not give time for the oil to wet the interface completely, and localized scoring could occur. It is even possible that it will take the hub a few minutes to pop out.

If the machine is very cold, chances are the oil (which becomes more viscous at low temperatures) will not completely penetrate between the hub and the shaft, and the hub cannot be removed. One solution to this problem is to apply some heat to the hub. However, heating the hub above 250°F can be detrimental. First, because oils will lose much of their lubricating properties, and second, because O-rings can be scorched and will no longer seal. Therefore, heat is best used in moderation, and as a last resort.

In order to eliminate all risks related to hydraulic hub removal, a procedure which requires the use of the installation tool (Figure 4) during disassembly was developed many years ago by Calistrat. This procedure consists of the following steps:

Remove the shaft nut.

☐ *Mount the collapsed installation tool.* Wet the shaft threads with thin oil and rotate the tool until it butts against the shaft shoulder. Verify that a gap exists between the tool and the hub, equal to or larger than the amount of advance used when the hub was installed (check the records). If the gap is less than required, the wrong installation tool was probably selected for removal.

☐ *Connect the hydraulic lines.* Connect the installation tool to the low-pressure oil pump (5,000 psi minimum). Connect the high-pressure oil pump (40,000 psi minimum) to the hole provided either in the center of the shaft or on the outside diameter of the hub, depending on the design. Both pumps must be equipped with pressure gauges. Loosen the vent plug of the installation tool and pump all air out; retighten the plug.

☐ *Pump oil into the installation tool.* The piston will advance until it contacts the hub. Continue pumping until the pressure is between 100 to 200 psi. Check for leaks.

☐ *Expand the hub.* Pump oil between the hub and the shaft by using the high-pressure pump. While pumping, watch both pressure gauges. When the high-pressure gauge reaches about 20,000 psi, the pressure at the low-pressure gauge should start increasing rapidly. This pressure increase is caused by the force that the hub exerts on the installation tool, and is an indication that the hub is free to move. Note: depending on the interference used and on other conditions, the dilation pressure could reach 35,000 psi, before the hub will start moving.

☐ *Wait a while*. In case the low pressure at the installation tool does not increase even if the high pressure reaches 30,000 psi, wait about one-half hour while maintaining the pressure. It takes time for the oil to penetrate in the very narrow space between the hub and the shaft. Usually, there should be no need to exceed 30,000 psi unless a very high interference was used at installation.

☐ *Allow the hub to move*. After the pressure at the installation tool increases, slowly open the valve at the low-pressure pump (note: this valve could become hot, as the energy stored in the hub is dissipated there; wear protective gloves). The oil from the installation tool will flow back into the pump and allow the hub to move. The pressure at the high-pressure gauge will drop. Do not allow it to fall below 5,000 psi. If it does, close the low-pressure valve and pump more oil at the high-pressure pump. Continue the process until the valve at the low-pressure pump is completely open and the pressure at the installation tool becomes zero.

☐ *Remove the hub*. Release the high pressure and back off the installation tool until only two or three threads are still engaged. Pump the high-pressure pump, and the hub will slide off the shaft. When the hub contacts the installation tool, release all the pressure and remove the tool. The hub should now come off the shaft by hand. Do not remove the installation tool unless the pressure is zero!

☐ *Inspect the O-rings*. Reusing even slightly damaged rings invites trouble. The safest procedure is to always use new seals and discard the old ones.

FAILURES CASES

As with any new device or method, failures are bound to happen in the beginning, either due to poor training, or to negligence. Although the risk of sudden release of stored energy can be dangerous, the authors know of no injuries related to hydraulic hub removal.

Case 1

In a chemical plant, a gas compressor was retrofitted with new keyless shafts. New couplings were purchased and installed. A few days after startup, one of the couplings spun on the shaft, which became severely damaged. A new shaft was made and a new hub was purchased. It was noticed during the installation that the force necessary for hub advance was much larger than expected. The hub was immediately removed, and a sheet of rubber was found on the shaft. What happened? The person who purchased the O-ring seals, unaware of the need for backup rings, ordered O-rings that were as wide as the grooves. Evidently, the seals were too large and exceeded the cross sectional area of the grooves. They became extruded between the bore and the shaft. Installation of correct seals solved the problem.

Case 2

A keyless hub could not be removed, because not enough pressure could be created to dilate it. The hub had to be cut for removal. Observation of the bore revealed that:

- Sand was trapped between the bore and the shaft. Sand granules prevented a good contact, but provided sufficient friction for torque transmittal.
- The backup rings were installed at the face (rather than back) of the O-rings. Combined with the gap at the interface created by the sand, the O-rings were blown off the grooves, and pressure could no longer be built.

Case 3

Seven out of eight coupling hubs in two compressor trains slipped on their shafts during operation. The hubs became welded onto the shafts, and the trains operated successfully until the first scheduled maintenance shutdown. The coupling hubs had to be cut off for removal. Observation of the bores revealed that the coupling manufacturer applied a dry coating on all coupling hub surfaces, including the bores, as protection against rust or corrosion. This coating acted as a dry lubricant at the bore, practically eliminating any friction. The problem would not have occurred if either the bores were not coated, or if the hubs had been lapped (they were not). To eliminate such occurrences, the manufacturer discontinued the dry coating method, and the user made lapping mandatory at installation. As a point of interest, the coated coupling hubs were installed by the compressor manufacturer, not by the user.

CONCLUSIONS

Hydraulic removal of couplings can be used either with keyed or keyless hubs.

The method has (apparent) disadvantages:

- Couplings cost more (but the additional costs are quickly recovered by shortening the removal time).
- Mechanics require better training.
- Specialized tools are required.

The method has many advantages:

- It is faster than brute force, and consistently successful.
- It eliminates the need of open flames.
- It eliminates the possibility of shaft and bore damage.
- In keyless hubs, it eliminates the stress concentrations created by keyways.

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