POWER MEASUREMENT IN U-JOINT DRIVE SHAFTS ON IRRIGATION PUMPING PLANTS

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ABSTRACT

A commercially available torque meter has been used to measure engine torque and horsepower on approximately 800 irrigation pumping plants. By using specially designed adapter flanges, the torque meter and six temporary drive shafts can be fitted to pumping plants having 18 combinations of drive shaft capacity and length. During the measurements, engine torque has been as high as 10,000 lbf-in. (1130 N-m), and engine speed has been as high as 3100 rpm.

INTRODUCTION

During the past two decades, several researchers have used instrumented U-joint drive shafts to measure the engine power of irrigation pumping plants (Texas Tech University, 1968; Abernathy et al., 1978; Adams and Carver, 1980; Schneider and New, 1986). Although the measurements have been described in detail, the power measuring equipment has not. In this article, we describe the power measuring equipment used by Schneider and New (1986), which is similar to that used by the other researchers.

The typical engine-powered irrigation pumping plant uses two Hooke or Cardan U-joints in the drive shaft to eliminate the need for exact alignment of the clutch and right-angle gear drive shafts (Fig. 1). Two U-joints are used because a single Hooke or Cardan U-joint does not deliver constant angular velocity when the joint is operated at an angle (Society of Automotive Engineers, 1979). By maintaining equal U-joint angles in the same plane and placing the inboard yokes in line, the fluctuations in angular velocity are compensated. Then, only the intermediate shaft accelerates and decelerates twice per revolution.

Two techniques can be used for locating a torque meter within a U-joint drive shaft. One is to place the torque meter within the intermediate shaft. The other is to place the torque meter outside the U-joints on the flange of either the clutch or right-angle gear drive shafts. We selected the exterior placement (Fig. 2) because the torque meter maintains constant angular velocity with constant engine speed. Exterior placement also allows more flexibility in connecting a torque meter into existing pumping plants.

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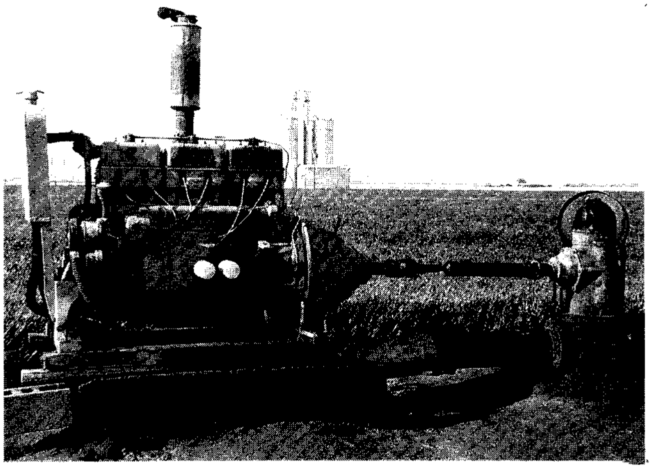

Figure 1–Typical U-joint drive shaft connecting an engine and a right-angle gear drive on an irrigation pumping plant.

EQUIPMENT DESIGN

In our design, the permanent drive shaft on an irrigation pumping plant is replaced with a temporary drive shaft and torque meter (Fig. 2). The torque meter is bolted to the flange on either the clutch drive shaft or the right-angle gear drive shaft. A shorter temporary drive shaft then connects the torque meter and opposite drive shaft flange.

We use a flange drive torque meter (Fig. 3) which requires only 4 5/16 in. (109 mm) space between the two flange faces. The torque meter, manufactured by Lebow Associates, Inc.*, weighs 17 lbs (7.7 kg) and has a torque

*Mention of a trade name or product does not constitute a recommendation or endorsement for use by the U.S. Department of Agriculture, nor does it imply registration under FIFRA as amended.

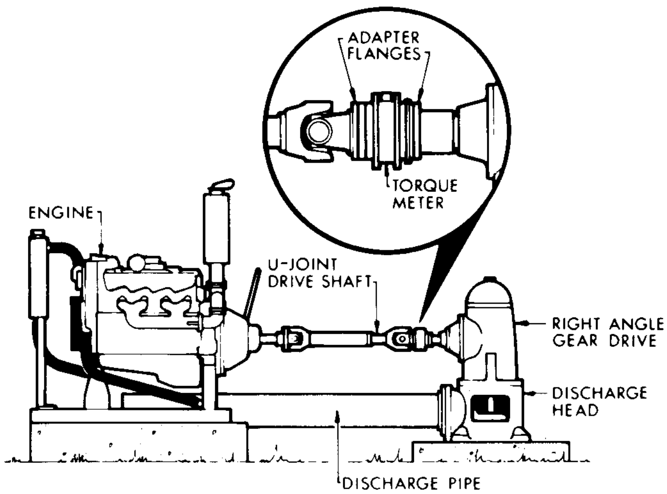

Figure 2–Instrumented drive shaft on an irrigation pumping plant.

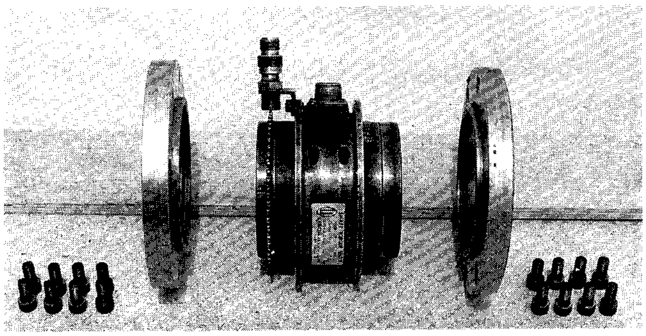

Figure 3–Torque meter with adapter flanges for connection to drive shaft flanges.

capacity of 20,000 in-lbs (2 260 N-m). The strain gauge torque meter also includes a speed sensor for measuring the drive shaft speed. Maximum torque during engine testing is approximately 10,000 in-lbs (1 130 N-m), but we selected the larger torque meter to handle the secondary couple created by the U-joint drive shafts. Maximum operating speed of the torque meter is 5,000 rpm or 1.6 times the maximum operating speed of the engines we tested. This safety factor and the large critical speed of the hollow tubing, intermediate shaft kept our operating speeds below critical speeds.

Practically all of the engine-powered irrigation pumping plants in the Southern High Plains use Spicer U-joint drive shafts. By examining pumping plants and obtaining information from equipment dealers, we determined that six different series drive shafts were needed. These six series are commonly used in lengths of 24, 36, and 48 in. (610, 914, and 1219 mm).

Torque meter adapter flanges are required because the flanges of the torque meter and Spicer drive shafts are different (Fig. 3). One side of these adapters matches the bolt pattern and centering ring of the torque meter. The other side matches a Spicer Series 1610 drive shaft flange. On the drive shaft side, the Spicer flange has a female pilot; and on the gear drive side, the Spicer flange has a male pilot. To have flat surfaces on the flanges, we counter-bored the bolt holes and use Allen-head cap screws. With this design, the torque meter adapter flanges never have to be changed when we move from one pumping plant to another.

To reduce the quantity of test equipment, we used additional adapter flanges and two series of U-joint drive shafts. From the two drive shaft series, we adapted either up or down or in both directions. The permanent drive shafts are designed for continuous service, and our testing is intermittent service. We are, thus, able to use drive shafts one size smaller for our intermittent testing. Use of the adapter flanges enables us to replace 18 combinations of drive shaft torque capacity and length with only six temporary drive shafts. Each series drive shaft has a fixed-length end with a male spline and a variable-length end with a female spline. The fixed-length end can be used for all three lengths of a series, further reducing our equipment inventory.

Our basic drive shaft arrangement utilized a shortened Spicer Series 1610 U-joint drive shaft (Fig. 4). With this arrangement, the torque meter and adapter flanges act as a spacer in series with the drive shaft. The shortened drive shaft connects directly to the clutch flange on one end and

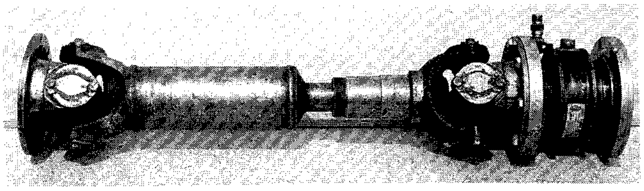

Figure 4–Spicer series 1610 drive shaft requiring only the adapter flanges on the torque meter.

to one torque meter adapter flange on the other end. The second torque meter adapter flange connects directly to the gear drive flange.

To adapt to three additional drive shaft series, we add one adapter flange at each end of the basic arrangement (Fig. 5). The three drive shaft series include one that is larger and two that are smaller. Fitting two adapter flanges together requires that one set of bolt heads be recessed into the flange. Just as with the torque meter flanges, we counter-bored one set of bolt holes to use Allen-head cap screws.

For our two smaller drive shaft series, we substituted a Spicer Series 1410 drive shaft in place of the Spicer Series 1610 drive shaft. The arrangement is similar to that of Fig. 5 except that we used one additional adapter flange between the drive shaft and torque meter. This flange fit the Series 1610 flange on the torque meter side and the Series 1410 flange on the drive shaft side. The additional adapter flange is optional because the torque meter adapter flange could be machined to fit both the Series 1410 and 1610 flanges.

The electric signals from the torque meter must be processed to provide the required measurements. We use a Datronic system that calculates torque, shaft speed, and power and sequentially displays the three variables. Proper calibration and adjustment of the torque meter and electronic equipment is essential for accurate torque and power measurements. Although the Lebow torque meters are factory calibrated, the electronic equipment needs to be carefully inspected upon delivery and adjusted before each field use. The channel for the strain gage torque meter requires adjustment of the null and span controls. Other channels in the scanner usually have a calibration value that needs to be checked and adjusted. We make the checks and adjustments after installing the torque meter in the drive shaft and before starting the engine and pump. The torque meter has not required factory recalibration during our pumping plant testing.

Discussion

During nine years of testing, the instrumented U-joint drive shaft has reliably and accurately measured the engine power of approximately 800 irrigation pumping plants. Very likely, it could be adapted to other types of U-joint driven machinery where temporary power measurements

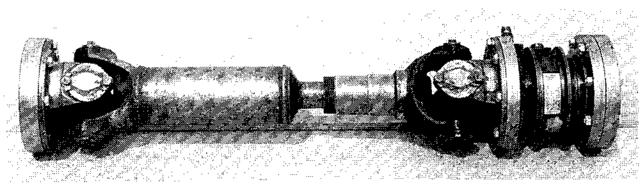

Figure 5–Spicer series 1610 drive shaft with additional adapter flanges on each end to replace a smaller drive shaft.

are needed. Our field experience could be helpful in planning this type of test equipment.

The main problem we encountered was fitting the instrumented drive shaft into the space allowed by the permanent drive shafts. Splined extensions in the drive shafts allow a deviation of about ± 1.25 in. (± 32 mm) from standard lengths. If the drive shaft opening is not within these limits, we cannot use the instrumented drive shaft without moving the engine. Our equipment utilizes standard Spicer drive shaft flanges, so nonstandard flanges make some power measurements impossible. Finally, damaged flanges or forward flange keys on the engine or right-angle drive cause delays or make power measurements impossible. Spicer flanges have pilot rings for precise centering of two mated flanges. If the centering rings were damaged when we removed the permanent drive shaft, installing our drive shaft was difficult or impossible.

If new pumping equipment is being purchased that will be efficiency tested, the number of drive shafts and flanges can be reduced considerably. The best choice is to select a single drive shaft length. The next step is to minimize the number of drive shaft torque capacities or sizes. If a standard length and capacity are possible, only torque meter adapter flanges and a single-drive shaft will be required.

Safety needs to be strongly emphasized while using the torque-measuring equipment. Every effort must be made to connect the adapter flanges to the same specifications as the permanent drive shaft flanges. Pilots of the flanges must be accurately aligned, and all bolts must be securely tightened. If any two flanges cannot be securely connected, the flanges must be repaired or the test abandoned. The same must be done if any bolt cannot be securely tightened. All pumping plants to be tested must have good bearings in the gear drive and clutchshafts, and the shafts must be parallel and in a plane. A shield over the temporary drive shaft is desirable. If a shield is not used, all personnel must be kept clear of the rotating drive shaft.

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