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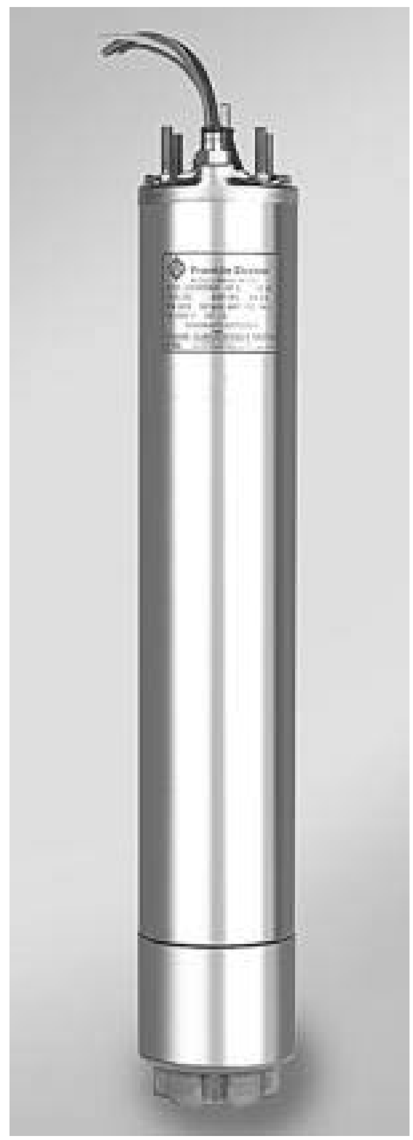
# The 4" Motor Puzzler



Towards the end of the 20th century, pump installers began to report unusual failures in some of their 4” submersible well pump installations. By unusual, I mean destruction! They found twisted or broken pump shafts, stripped splines, and even broken motor shafts. The common thread was that most involved pumps installed on 5 HP, single phase, 4” Franklin motors. Few, if any, three phase installations experienced any of these problems and smaller single phase installations seemed equally immune as well.

What is the source of these problems? Are pump manufacturers or that venerable motor manufacturer lowering the quality of their materials? Is mass production the culprit or could it be sloppy assembly in the field? Fortunately our faith in these products can remain in tact as none of the aforementioned reasons were the cause. It is just another example of physics biting us on the butt when we don’t pay attention to its laws

# THE 4" MOTOR PUZZLER

Nikola Tesla Meets Isaac Newton

Joe Evans, Ph.D

This Puzzler is not intended to cast dispersions on Franklin Electric or any of the pump companies that use its product. Its just a good example of what can happen when progress ignores basic physics.

In our competitive, free market society, pump manufacturers strive to take advantage of every ounce of horsepower a motor can provide. After all who would want to market a pump that delivers only 90% of that of his competitor? But when we push a product to its limits unexpected results can occur.

Shaft damage is not all that uncommon in constant torque applications (ie positive displacement pumps). Variable torque applications (ie centrifugal pumps), on the other hand, usually do not share this problem. What happened in this instance is that two branches of physics (electricity and mechanics) worked together to produce these undesired results. That these failures were limited to a single model is, at first, a bit puzzling but a brief look at the simple physics involved will make it quite clear.

**The Tesla Side of the Coin**

The modern electric motor, invented by Nikola Tesla, operates via the principle of induction.[1] A current in the motor's stator creates a magnetic field which in turn "induces" a current in the rotor. The magnetic field produced by the induced current opposes (like NN or SS magnets) the field in the stator and the force produced causes the rotor to rotate. The speed (RPM) at which the rotor rotates depends upon the frequency of the current and the number of fields (poles) produced in the stator.

If one were to wind a single phase stator in a manner that creates two winding groups 180º apart, the result is referred to as a two pole motor. Since AC current in the USA alternates sixty times each second (60hz), the two poles are energized a total of sixty times during one second's time. If the rotor could respond effortlessly to these opposing fields, it would rotate at 3600 RPM (60 X 60). But in the real world, outside forces reduce this theoretical (synchronous) speed to a lower value. Actual speed, often called slip speed, hovers between 3450 and 3550 RPM.

Now, if we were to increase the number of poles to four (90º apart), it would take twice as many cycles for the current to circle the stator's windings. The result is a motor that rotates at 1800 RPM. Increase the number of poles to six (60º apart) and rotational speed drops to 1200 RPM. Theoretically this could go on forever but, at some point, one runs out of room or the stator becomes impracticably large.

When AC current in the stator induces a current in the rotor, the rotor undergoes acceleration and continues to accelerate as long as the magnetic fields oppose one another. When the fields subside, the rotor ceases to accelerate and, immediately, begins to slow. How much it slows depends upon the distance (in degrees) to the next magnetic interaction. With a six pole motor the distance is only 60º but in a two pole motor the rotor must travel three times that distance before it is reaccelerated. Because this distance is so great two pole, single phase motors incorporate a set of "start" windings that serve to reduce this distance during starting. Three phase motors do not encounter this distance problem because each phase has its own set of poles. A three phase, two pole motor actually has six distinct poles 60º apart. By timing the phases properly, it can still operate at 3600 RPM but does so with the help of three times as many induced accelerations per unit of time.

[1] For a basic introduction to electric motors and induction see "The Three Phase Induction Motor" located on the Education page of our web site. www.pacificliquid.com/motorintro.pdf

## The Newtonian Side of the Coin

You have probably already deduced (a little reverse induction humor) that the time between reaccelerations in the two pole, single phase motor is the cause of the failures described in the puzzler. But why does it occur in just the 5 HP model? After all the 1/2 - 3 HP models operate in exactly the same manner. And, why not the 5 HP, 6" model? Should it not experience similar problems?

1) In part, Newton's First Law (inertia) states that an object in motion will remain in motion at a constant velocity unless it is acted upon by some outside force. In the case of a submersible electric motor, these outside forces are friction (radial and thrust bearings) and the load produced by the pump.

2) In part, his Second Law says that the acceleration that an object undergoes when acted upon by a force will be directly proportional the size of the force and inversely proportional to the mass of the object. Therefore a more massive motor rotor will accelerate more slowly than a smaller one when acted upon by the same force. But, the reverse is also true! The more massive rotor will also decelerate more slowly than a smaller one.

It is this combination of deceleration, acceleration, and the time lapse between the two that is the real culprit. The torque required to reaccelerate the 5 HP rotor, under these conditions, can be considerably more than normal.[2]

As I mentioned earlier, shaft and coupling problems are common with reciprocating machines. Although they are called "constant torque" machines, the torque required at different points of a single operating cycle is anything but constant. Take the single acting piston pump for example. Much more torque is required during the discharge portion of the pumping cycle than is required during the suction portion. Therefore during each pumping cycle torque will peak and then subside. Even the double acting pump undergoes torque peaks during its pumping cycle. The common method of evening out these torque demands on a motor is the incorporation of a flywheel.[3] The flywheel adds additional inertia to the process and helps to unload the motor during times of peak torque.

The more massive rotor of the 6" Franklin motor acts like a flywheel and adds additional inertia to the process. The lower horsepower 4" motors also tend to be immune because their rotors are also quite massive relative to their power output. It is only the 5 HP model, whose rotor is not that much larger than the 3 HP unit but produces over 60% more HP, that is subject to the failures described in the puzzler. Because of its relatively low inertia and higher loading, it decelerates more quickly between induction cycles. The torque required to get it back to speed becomes higher than normal and creates a "torque pulse" that can potentially damage the rotating components.

So what can be done to alleviate this problem? Probably the easiest fix is not to load the motor to the max but, that will be difficult as long as competition exists. Another, more probable, outcome is to beef up the motor and pump shaft components. Regardless of what is done, the problem will never go away, but it probably can be made tolerable.

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[2] For a review of torque see the "My Shafts Bigger Than Yours" Puzzler on the Education page of our web Site. www.pacificliquid.com/puzcomplete.pdf

[3] For a review of flywheels and rotational inertia see the "WK2" Puzzler located on the Education page of our web site. www.pacificliquid.com/puzcomplete.pdf