# Shaft Design for Industrial Tank Agitators

White Paper

Five Primary Variables of Shaft Design

How to Prevent Fatigue Failure in the Gearbox Shaft

When and When Not to Use a Steady Bearing

PROQUIP

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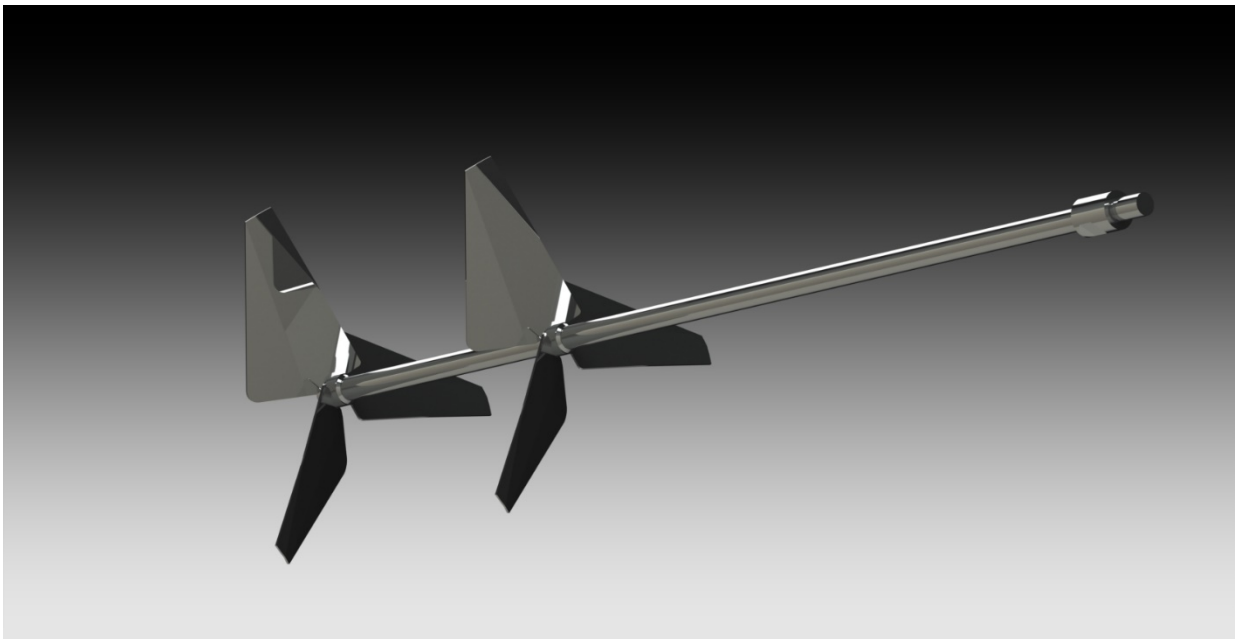

Shaft design is critical to the performance of your industrial mixer. This white paper explores the following topics related to shaft design:

- The five primary variables of shaft design
- How to prevent fatigue failure in the gearbox shaft
- When and when not to use a steady bearing

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## Five Primary Variables in Industrial Mixer Shaft Design

The five primary variables in industrial mixer shaft design are length, weight, torque, hydraulic loading, and stiffness.

*1. Length of the Industrial Mixer Shaft*
The length of the industrial mixer shaft is primarily determined by the desired location of mixing impellers in the vessel. This is directly related to the geometry (e.g., size and height) of the mixing vessel.

*2 -4. Weight, Torque and Hydraulic Loading of the Industrial Mixer Shaft*

The weight, torque and hydraulic loading of the industrial mixer shaft are determined by the impeller, which is itself, determined by your process requirements. The design of the industrial mixer shaft must be able to handle the torque and bending moment induced by its impeller.

Modern designs for industrial mixer impellers often put more stress on the mixer shaft caused by bending moment than the stress caused by the torque required to power them. Consequently, while a commodity gearbox comes with an output shaft diameter commensurate with its torque rating, a gearbox specifically designed for industrial mixer applications comes with a larger shaft that allows for the bending moments typical of mixing applications.

*5. Stiffness of the Industrial Mixer Shaft*
One free variable in industrial mixer shaft design is its stiffness, which is directly related to its diameter. The diameter of your industrial mixer shaft must be large enough to withstand the stress brought about by the combined torque and bending forces on it. The diameter of your industrial mixer shaft must also be large enough to keep the critical speed sufficiently above the operating speed to prevent excessive vibration. Proper industrial mixer shaft design does not allow the critical speed limit to be the controlling factor on the shaft diameter.

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## How to Prevent Fatigue Failure in the Gearbox Shaft of Your Industrial Mixer

A good industrial mixer design cannot use a gearbox that has an output shaft significantly smaller than the mixer in tank shaft, even if the overall critical speed of the system would be sufficient. A large change in stiffness close to the top of the shafting (where the small gearbox shaft is coupled to the large tank shaft) concentrates the shaft deflection on the smaller diameter. The result is ultimate fatigue failure of the gearbox shaft.

The industrial mixer designer can address this problem in two ways. First, they can choose a gearbox with an output shaft about the same diameter as the tank shaft. When critical speed controls the diameter, this will require a gearbox capable of handling significantly more torque and bending than is actually required by the application. The result is a gearbox with a very high service factor that is more costly than required by the industrial mixer motor size and less efficiency because it is under loaded.

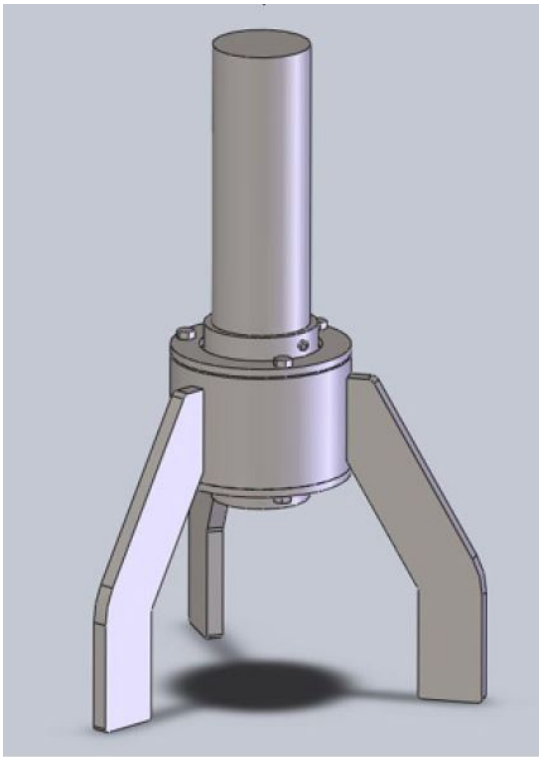
The second way to avoid fatigue failure of the gearbox shaft is to mount the tank shaft in bearings in the gearbox support pedestal. The gearbox can then be chosen based on the power required, and it can be flexibly coupled to the top of the tank shaft. However, this can result in a more complicated mounting arrangement and require additional maintenance and spare parts. The gearbox cost reduction versus the increase in cost of the shaft mounting on larger pedestals is often “a wash.”

Other factors related to the shaft diameter of your industrial mixer will result in indirect costs including larger impeller hubs and shaft couplings. The in-tank assembly will also be heavier than required by the torque and bending loads if critical speed considerations had not controlled the minimum shaft diameter.

## When to Use a Steady Bearing for Your Industrial Mixer Shaft Design

Steady bearings have been used with mixing equipment for the past 400 years and are an important design consideration for your industrial mixer shaft. However, most industrial mixers today do not use them.

So what is a steady bearing? An industrial mixer steady bearing is a guide bushing that is usually installed in a mounting on the floor of the mixing vessel. The end of the mixer shaft is inserted into the bushing. The steady bearing restricts shaft deflections caused by unbalanced hydraulic loads induced by mixing.



*Steady bearings have been used with mixing equipment for centuries, but often are not used today.*

A steady bearing helps solve the critical speed design problem for industrial mixers. When the bottom of the shaft is constrained, its mode of vibration changes. The maximum deflection is approximately at the midpoint of the shaft instead of at the end. In this vibration mode, the natural frequency or critical speed is much higher than an unsupported shaft. Since the industrial mixer designer has already chosen its operating speed, they can use a significantly smaller shaft diameter along with the steady bearing support. Furthermore, the steady bearing resists the lower most impeller side loads and keeps them from being transmitted to the gearbox or pedestal as bending moment.

The combination of the above benefits can result in significant cost savings, lighter weight and lower loading on the nozzle or beams that support your industrial mixer. In some cases, the reduction on bending moment alone results in significant indirect savings.

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## Three Reasons Steady Bearings are not Used in Industrial Mixer Design

The first reason a steady bearing often isn't used is increased maintenance. Steady bearings wear out relatively quickly compared to most other industrial mixer components. Most steady bearings should have the bushing and wear sleeve replaced about once a year. An initial steady bearing installation should be inspected after the first six months of operation to ensure more frequent changes are not necessary.

From a mechanic's point of view, it is generally easy to replace a steady bearings' wearing components. ProQuip always uses a wear sleeve on the end of the industrial mixer shaft. The wear sleeve slips over the bottom end of the industrial mixer shaft and can be easily replaced. Likewise, the bushing is inserted in the housing and held with retaining plates that allow changing it without disturbing the rest of the industrial mixer installation. The metal sleeve wears more than the elastomer bushing in about 90% of cases, but they should be replaced together.

A problem with changing these wearing components is that someone has to physically enter the mixing vessel. In many cases, mixing vessel entry is potentially dangerous and must follow a specific procedures. If you are not familiar with your company's mixing vessel entry procedure, contact your safety manager. An especially hazardous mixing vessel entry can take a week of preparation and may require a complete process shutdown.

The second reason a steady bearing is not used in many industrial mixer applications is process incompatibility. Only a few bushing materials are approved for steady bearing use and all have limits:

- Elastomers – application limits
- Bronze – incompatibility with many materials and processes
- Cast iron – very limited applications
- Polytetrafluoroethylene (PTFE) – temperature restrictions

The steady bearing is normally lubricated and cooled by the vessel contents. You should never operate a steady bearing unit for a prolonged period of time without liquid coverage. Moreover, there are many materials that will polymerize, crystallize or otherwise react in high shear annulus between the bushing and the sleeve. This condition can make the use of a steady bearing impractical for your industrial mixer application.

Finally, a steady bearing may also be a poor choice for use in an abrasive slurry. Although a steady bearing can be equipped with a flushing system for the annulus, this is an additional expense and must be carefully maintained. Flushing systems can also be used for sanitary applications, including the capability for steam flushing. However, flushing will not prevent wear and the steady bearing will still have to be serviced on a regular basis.

## For More Information

For additional information on design considerations for industrial mixer shafts, go to the ProQuip shaft design overview, complete the ProQuip Applications Data Sheet or contact us at 330-468-1850 or applications@proquipinc.com.