White Paper

Mixer Service Factors

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A common understanding of the term Service Factor (also known as Safety Factor) as it relates to the design, manufacture and sale of mixing equipment is useful and important to all involved in the effort to provide quality competitive products.

Cleveland Mixer Service Factors

This briefing paper is intended to provide some technical and commercial background into this term and how it relates to our products and business.

Service Factor

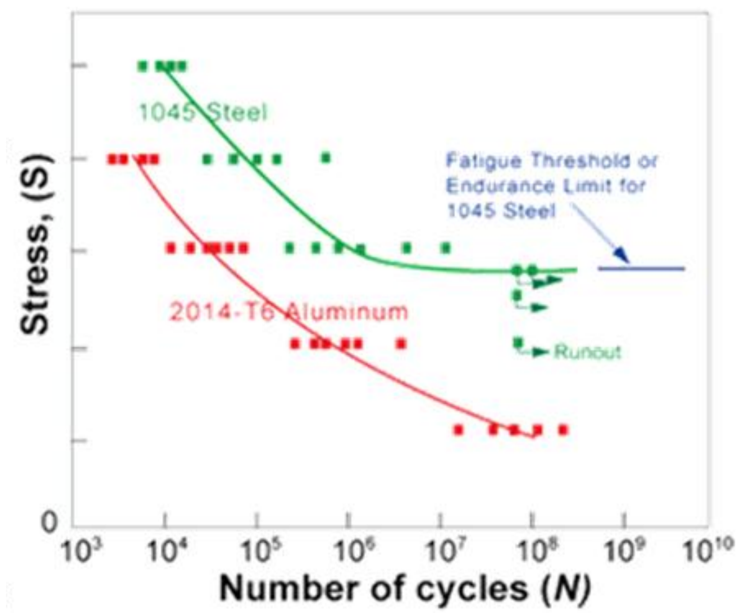
Service Factor is typically defined as a ratio of the capacity of a system or component to its intended or actual applied load. This is intended as a measure of reliability for the design of a system or component and can be expressed as :

$$\text{Service Factor (SF)} = \frac{\text{Capacity Load}}{\text{Applied Load}} = 1.0 \text{ to } 2.0 \text{ or greater}$$

Capacity represents the maximum strength of a system or component that if not exceeded will provide the intended or quoted life expectancy in hours, years or load cycles. It is very important to understand that the theoretical strength used in capacity determinations are primarily based upon material fatigue stress limits and are therefore statistical by nature. Probably the most common reference that demonstrates this relationship is the use of the term L_{10} for the basic life rating in bearings. This term and procedure is covered in ABMA (American Bearing Manufacturer's Association) Standard Number 11 "Load Ratings and Fatigue Life for Roller Bearings". L_{10} is defined as the life that 90% of a large group of bearings will survive under identical conditions. L_{50} is defined as the median life and is roughly five times the L_{10} life and is sometimes referred to as the MTBF (Mean Time Between Failure) life.

Endurance Limit

An important characteristic of fatigue life determination is that the relationship between stress and life in terms of stress loading cycles is exponential. This is an inverse relationship that shows a large increase in life cycles for each decrease in load stress. A typical S-N curve for Steel and Aluminum is shown below:



This plot shows the important difference between very ductile materials and less ductile to brittle materials. The steel in the plot shows a minimum stress level below which, the number of load cycles seems to never decrease. This point is called the Endurance Limit and is useful as a design stress limit for most of the metals found in Mixers such as round and flat bar, plate, gears, bearings and fasteners. This plot also points out that some materials don’t have a clear inflection point and therefore must be used for design with extreme care.

This table points out that a simple statement of rated bearing life in motors and gear drives must be carefully analyzed and applied with as much knowledge about the equipment and process as practical.

Stress and Load Cycles

This very important relationship between Stress and Load Cycles is important to understand when applied to Service Factor. Mixers are made in all different styles, sizes and speed of operation. Customers usually have an ideal of the length of life they want for their capital purchases but may not specify it. Therefore Cleveland Mixer and others usually refer to a period of years or in hours of L_{10} life where bearing life is determined to be the most susceptible cause of failure. Motor and gear drive manufacturers often tout the bearing life capability as a measure of reliability. Keeping the concept of stress cycles in mind, it is instructive to look at the relationship between mixer shaft rpm and stress cycles as shown below:

Mixer Shaft RPM	Stress Cycles per Hour	Hours/ 1,000,000 cycles	Hours/ 90,000,000 cycles	Years/ 90,000,000 cycles
33.33	2,000	500	250,000	28.50
100	6,000	167	15,030	1.72
350	21,000	48	4,320	0.50

Catalog bearing ratings (per ABMA Standard 11) are based upon testing to 1,000,000 cycles in 500 hours while some manufacturers provide comparative ratings for testing at 90,000,000 cycles. As this table points out, a simple statement of rated bearing life in motors and gear drives must be carefully analyzed and applied with as much knowledge about the equipment and process as practical.

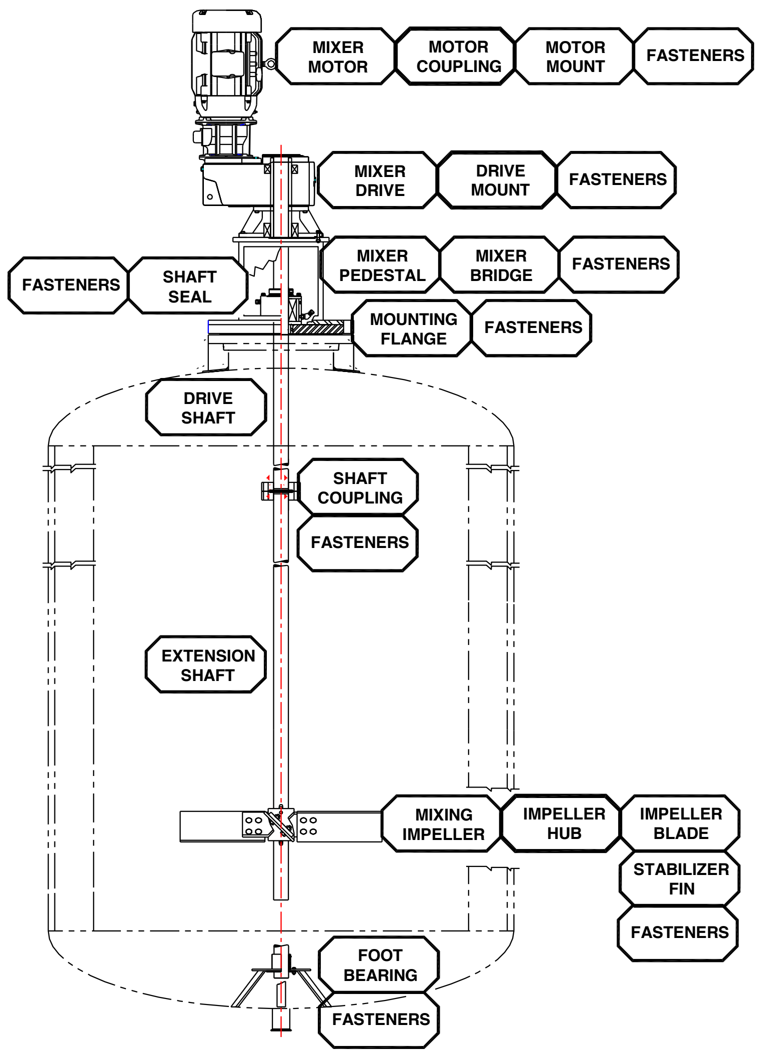
Quality and reliability improvement programs in all phases of the supply of mixing equipment process are aimed at reducing the variability in the performance and life of the equipment.

All of these ratings are based upon the design, manufacturing capability, material selection and quality, as well as operation in the field as planned by the equipment or component supplier. Each of these parameters that combine to make up the capacity portion of the calculation are also probabilistic in nature. For example, design is based in part on allowable stresses as if each material selection had a single point value for yield or ultimate strength. In reality, all materials are subject to a range of property values based upon quality of the raw materials and the accuracy and repeatability of the process by which they were manufactured. This same potential variability exists in the design process, the equipment manufacturing process and in the deployment and use of the equipment in the field.

Quality and reliability improvement programs in all phases of the supply of mixing equipment process are aimed at reducing the variability in the performance and life of the equipment. Such things as increased use of computerized analysis and modeling during design, more physical testing of products, increased inspection and optimization of manufacturing, and improved mixer selection processes as well as customer support and training are all aimed at reducing this variability in expectations.

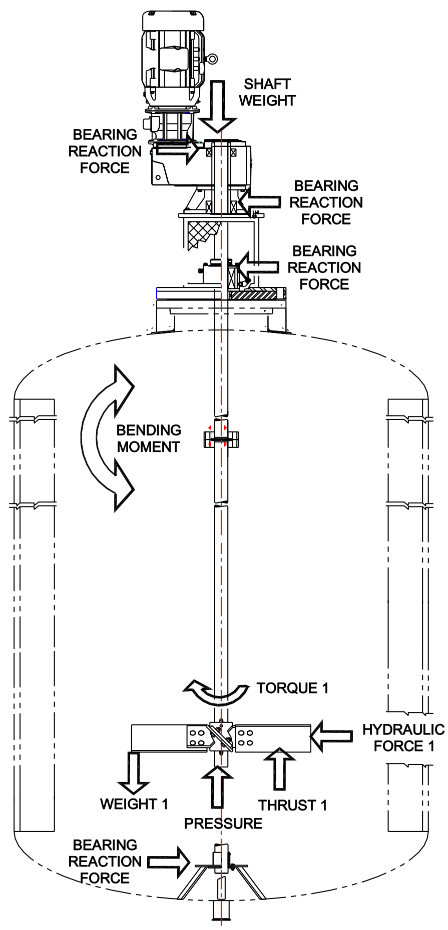
Service Factors are useful to provide an increased margin of reliability in our mixer selections in an attempt to guarantee that each customer will get the useful life from our mixing equipment that was expected. The simple solution is to increase Service Factor values until there is minimal possibility of failure but this can obviously lead to overdesign and non-competitive pricing. The competitive solution is to strive to better understand the design, manufacture and field deployment of each mixer selection in an attempt to optimize the selection for price and performance.

Key to that better understanding is the knowledge that each mixer is made into a system from a series of components, each with their own capabilities, variabilities and Service Factors made during their own design and selection. For a wide range of Cleveland Mixer products, the mixer system can be represented by the individual components as shown in the figure below with each tag calling out a specific design checking process that must be followed to determine the capacity of each component.



In most cases, Cleveland Mixer products are made from standard components that have been used before and have a capacity that is well understood. For purchased items such as the motors and gear drives, the vendor selection and engineering data becomes important as well as the ability to work together to validate their components' capacity in a specific mixer configuration. For new or very custom mixer configurations, components must have a detailed design check completed along with a risk evaluation for the level of uncertainty in the application.

This detailed design check of components is driven by a good understanding of the methods and magnitude of mixer loading during operation. This is critical to be able to translate the basic speed, horsepower and geometry selection for each mixer into accurate stress levels in each component to compare to the capacity value.



This figure shows the typical array of loads that must be analyzed to design not only the mixer but its supporting structure as well.

Once all of the components have been designed or otherwise selected, a final agitator system overview which uses dynamic analysis techniques is used.

Dynamic Loading and Analysis

The Mixer Service Factor final determination must consider the probabilistic nature of each of the capacity and applied load calculations as discussed. However, the applied loading has one further complication due to the potential additional loading from the dynamic response from the naturally harmonic motion of the rotating mixer systems. Strength and mechanics of materials are used to analyze the loading and determine stress levels throughout this process but the basic work is done under the principles of a static analysis. Mixers and their mountings can combine to cause potentially damaging dynamic loadings through vibrations and even serious and sometimes catastrophic operations at a critical speed or natural frequency.

Once all of the components have been designed or otherwise selected, a final agitator system overview which uses dynamic analysis techniques is used. This final step is necessary due to the relationship of transmissibility or stress amplification from operation near a critical speed.

The figure below shows the exponential relationship between transmissibility or possible stress amplification of system loads as the mixer operating point approaches the first critical speed of the overall installed mixing system.

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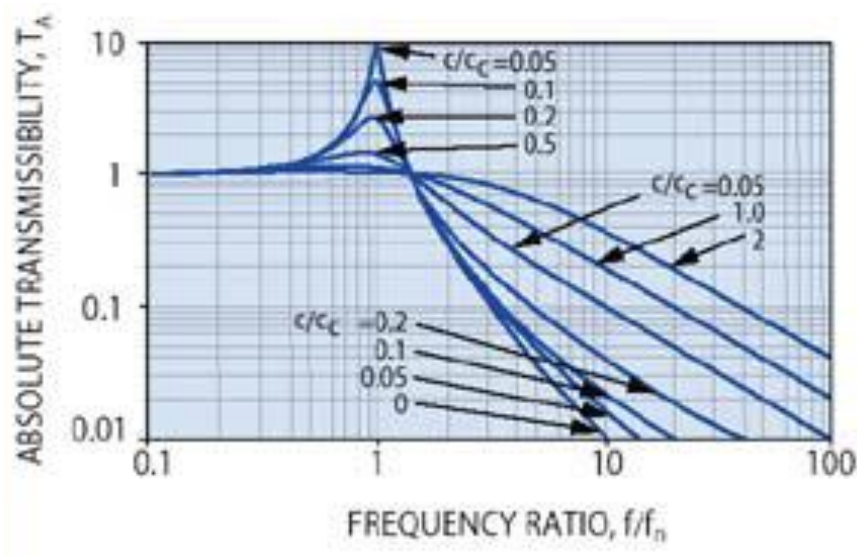

As this plot shows, operation of a mixer near a critical speed (f/f_n) can cause the normally calculated applied stresses to be multiplied depending upon the degree of damping (c/c_c) in the process system. Unchecked, this phenomenon simply removes any margin that was added to the life calculations through the use of Service Factors.

Conclusion

Cleveland Mixer is constantly improving its engineering technology to streamline and improve the design and analysis process for all of its manufactured and in many cases proprietary components. Sophisticated 3-D mechanical design and Finite Element Method based upon static and dynamic analysis are being used on all new design and for back checking and moving old designs to a validated standard data base. In addition, new efforts to involve critical component (motors and gears) vendor engineering functions are aimed at improving the understanding of Mixer System Capacity and the effects of the real Applied Loads as we strive to optimize our practice in the use of Mixer Service Factors.