

ENGINEERING NOTE

MECHANICAL

ANALYSIS OF SHAFT FAILURES

Reducer or motor shafts that have failed without any signs of permanent shaft deformation can be caused by one of three means:

1. Bending Fatigue
2. Torsional Fatigue
3. Defective Material

Determining the mode of failure is essential if proper corrective action is to be taken. The following descriptions will help in determining how a shaft fails.

1. Bending Fatigue Failure

A bending fatigue failure can occur when a load applied perpendicular to the shaft exceeds the design limitations. These excessive overhung loads may be from sheaves, sprockets or gears which are too small or too far out on the shaft, overtightened belts and chains, or even misaligned shafts.

These loads cause the material fibers to be in tension on the side of the shaft toward the load and in compression on the side opposite the applied load. As the shaft rotates 180° the stresses are reversed. After another 180° rotation, the stresses are again reversed; back to the original condition. So for every revolution, the surface of the shaft at any point will be stressed for a maximum tension to maximum compression and back again. See Figure I. For a motor shaft, it could easily be 1700 times per minute.

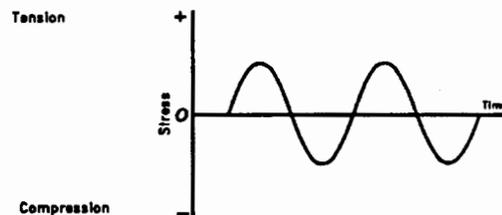


Figure I

ENGINEERING NOTE

MECHANICAL

These high stress reversals will cause a microscopic crack in the shaft material. These cracks will begin at the highest stress point on the shaft which may be at a keyway, a step, or even a scratch in the surface. Over a period of time, dependent on the severity of the overload, this crack will propagate or grow across the shaft diameter. As this happens, the cross sectional area is gradually reduced until it becomes too small diameter to withstand the load, at which point the shaft breaks suddenly.

The fracture face of a shaft that has failed from bending fatigue is composed of two distinct regions; the fatigue zone and the instantaneous zone. See Figure II.

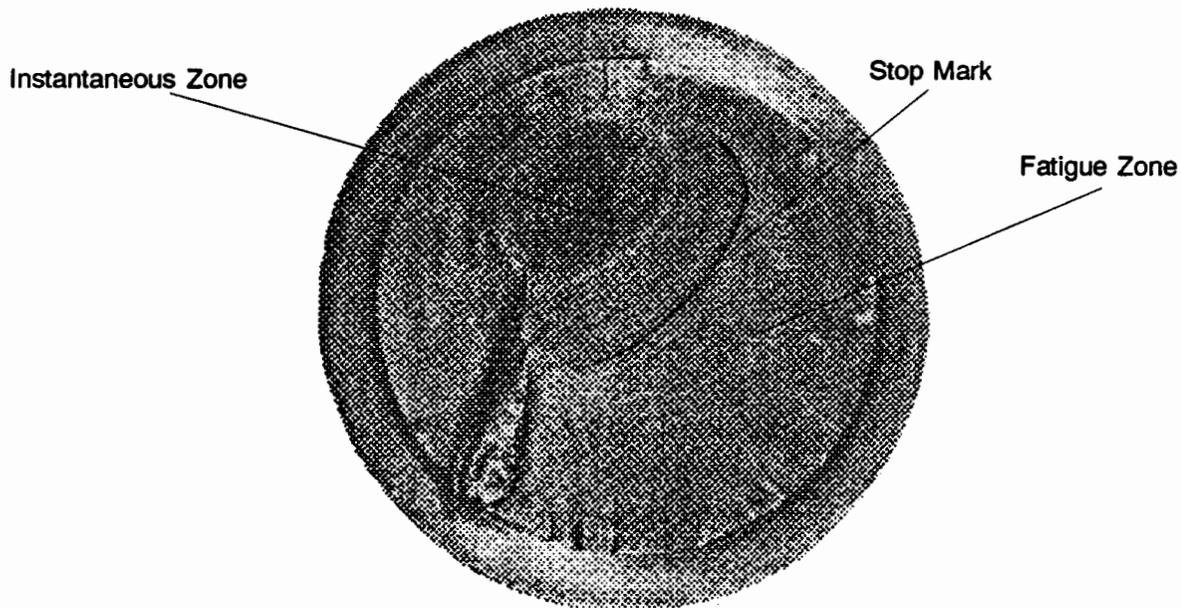


Figure II

The fatigue zone will be at the outer areas of the shaft. It is characterized by a smooth surface which is caused by the continual rubbing that takes place between the crack surfaces. The smoothed areas of the fracture is further identified in most failures by what are known as fatigue stop marks or "beaches".

ENGINEERING NOTE

MECHANICAL

The instantaneous zone will be toward the center of the shaft is characterized by a rough, grainy surface. This is the area that failed suddenly and did not get smoothed by the rubbing action that took place in the fatigue zone.

Once a fatigue crack has started from an overload, it can continue to grow even after the overload has been removed. When the shaft finally does break, it can happen with a very light load. For this reason, it is easy to think that the shaft might be defective because it failed at less than capacity load, but the evidence of the fracture itself will prove otherwise.

If it is determined that a shaft has failed from fatigue, corrective action must be taken or the replacement shaft will surely fail in the same manner. If a reducer shaft that was direct coupled failed, then the shaft it was coupled to was not properly aligned, or in the case of an unsupported agitator shaft, the shaft radial movement was excessive producing too much overhung load. Proper shaft alignment must be assured. If the shaft had a gear, sprocket, sheave, etc., then again the overhung load was too great. Gears, sheaves and sprockets must be of adequate diameter and located as close to the shoulder as possible. If the above recommendations cannot be achieved, then the reducer must be oversized to assure adequate shaft strength.

Reducer housings can fail from fatigue produced by repeated stress reversals. These are most often caused by insufficient mounting bases or improper mounting bolt tightening.

Gears may also fail by bending fatigue. The gear teeth are subjected to repeated stresses, one stress per revolution. When a gear tooth breaks off, it is because the tooth contact stresses are too high. This most often is a sign of overload which means the reducer has an insufficient torque rating. Another possibility is improper mounting which causes the housing to distort and thereby creating tooth to tooth interference.

2. Torsional Fatigue Failure

The appearance of a fatigue fracture caused by alternating torsion is quite different from that caused by bending failure. Torsional fatigue failures occur from the same reason as bending failures: excessive

ENGINEERING NOTE

MECHANICAL

loads causing repeated or reversing stresses. The difference is that torsional failures are caused by twisting the shaft as opposed to bending it.

Three basic patterns of failure in a shaft may be caused by torsional fatigue. There is one basic pattern for tensile and two for shear: transverse and longitudinal. Refer to Figure III for the basic patterns of failure and some of their variations. All cases should be distinguishable from the pattern of a bending failure.

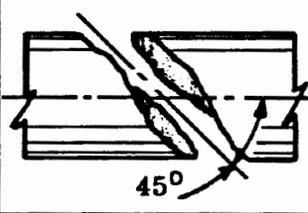
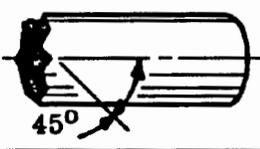
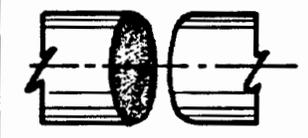
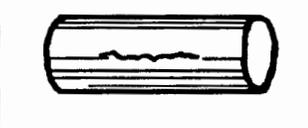
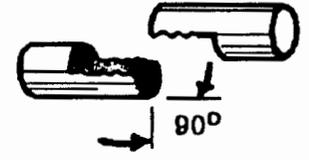
Type of Failure	Basic Pattern	Variations of Basic Patterns	
		(a)	(b)
Tensile 1		Star Pattern 	Saw tooth due to concentration at fillet 
Transverse Shear 2		Small Step 	Large Step 
Longitudinal Shear 3			

Figure III

Torsional fatigue failures are more often found on the intermediate gear shafts as opposed to input and output shafts where failure is most often due to bending. The intermediate shafts are exposed to

ENGINEERING NOTE

MECHANICAL

relatively small bending forces, but see very high twisting forces. A reducer subjected to very high shock loads or plug reversals may eventually fail by torsional fatigue. The reducer may have sufficient torque capacity to handle the load but insufficient service factor to handle the extra forces produced by the shocks. The reducer must be oversized to handle the shock.

3. Defective Material

In this day of "space age materials", a failure caused by a defect is becoming rare, almost to the point of extinction. A failure due to defective material is caused by two things: shaft breakage with out exceeding the design capacity, and a flaw in the grain structure of the material. Both must be present together to qualify for this type of failure. A flaw in the grain structure may be visible to the eye, or it may be microscopic, such as might be found in the case of improper heat treating, or not using the correct material.

The shaft may fail in bending or in torsion as described previously. The difference will be fact that no overload occurred. In most cases of failure, an overload may not be obvious. However, if the material structure is not defective, than an overload most certainly occurred at some point during the life of the drive.