HOW DO YOU AVOID JAMMING?

Jamming is a well-known problem during the assembly of parts with narrow tolerances (such as mounting a shaft in a hole). If the parts are not precisely aligned, they will get stuck and a high force is required to loosen them which often results in (unnoticed) damage on both parts. It is difficult to overcome jamming during the manufacturing process. However, if recognised during the design process, simple solutions to avoid jamming during assembly can be implemented.

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Introduction
A well-known and frequent problem during the assembly of parts with narrow tolerances is jamming (in Dutch: schranken), for example during the assembly of a gear on a shaft. Due to a small misalignment of the shaft and the hole in the gear, the parts get stuck. Pushing harder to force the shaft through the hole does not help, but only jams the shaft even more. A realigning force (read: hitting with a hammer) is needed to release the shaft.

During the jamming and loosening of the parts, large forces will occur on small surfaces resulting in high local stresses (Hertz contact). These high stresses will lead to damage on both parts; this damage is often not noticed and the consequences are often unknown. To avoid damage, the clamping of the parts should be disengaged before they get stuck.

The problem of jamming occurs during assembly and can be solved with craftsmanship or, when recognised, with tooling which helps to align the parts within the angle under which jamming will not occur. However, this is not always easy to do, which means that the issue of jamming can be inherent to the design.

Therefore, it would be best to apply the Design for Manufacturing (DfM) methodology and solve the issue during the design stage instead of dealing with the problem during the manufacturing stage. When designed correctly, it should be possible to assemble a precise shaft-hole combination with just one hand.

A simple solution to avoid jamming is presented here. The first part of this article describes how to recognise during the design phase whether the risk of jamming is present. An equation is presented for identifying the risk of jamming, based on the geometry of the shaft and the hole, the angular position with respect to each other and the friction coefficient.

In the second part of this article, a practical solution is given as to how the design can be adapted to avoid jamming during assembly.

Finally, a methodology is proposed that includes the risk determination and design adaptations.

The risk of jamming
Usually jamming occurs during the initial positioning of the shaft in the hole. Especially if the gap between the shaft and the hole is small due to a small tolerance. As a result, the angle (α) between the shaft and the hole (Figure 1Fout! Verwijzingsbron niet gevonden.) under which the parts can be assembled without jamming, is small. This requires accurate placement of the parts. In manual assembly, this is left to the craftsmanship of the operator but, especially in...
automated assembly, the required accuracy of the placement should be known beforehand.

A mathematical model was created to compute the accuracy required to assemble the parts without jamming. A complete derivation is out of scope for this article, but is available on request. The model is based on the geometry and forces (friction, $W$, and normal, $N$) defined in Fout!

Verwijzingsbron niet gevonden. Figure 2 and shows that the system becomes self-aligning if the insertion length ($L_{in}$) is large enough.

This insertion length can be described with:

$$L_{in} = \left( D_{hole} - D_{shaft} \cdot \cos \alpha \right) / \sin \alpha$$

With $D_{hole}$ and $D_{shaft}$ representing the diameter of the hole and shaft.

Because the angle $\alpha$ is small, $\sin \alpha \approx \alpha$ and $\cos \alpha \approx 1$.

From the evaluation of forces (Figure 3), it follows that if $L_{in} > \mu D_{shaft}$, with $\mu$ representing the friction coefficient, the direction of the resulting force $R_1$ realigns the shaft with respect to the hole. In this case, the system is self-aligning and jamming will not occur.

The criterion $L_{in} > \mu D_{shaft}$ results in a maximum angle $\alpha_j$ for which no additional force is required to realign the shaft:

$$\alpha_j = \left[ \frac{D_{hole} - D_{shaft}}{\mu D_{shaft}} \right]$$

If the angle $\alpha$ during assembly is smaller than $\alpha_j$, jamming will not occur.

**Theoretical solution**

As previously stated, jamming only occurs if the insertion length is too small. Therefore, jamming is avoided if the insertion length $L_{in}$ is larger than the friction coefficient $\mu$ times the diameter of the shaft. Theoretically this can be done by making the end of the shaft ball-shaped.

The insertion length is elongated and because of the ball shape, it is easy to rotate the shaft without force. However, this theoretical solution has some disadvantages:

1. The effective length of the shaft is shortened
2. Making the ball shape at the end of the shaft is an expensive process

A more practical solution should increase the insertion length, but without these disadvantages.

**Practical solutions**

Two practical solutions to increase the insertion length are possible:

1. Adding a groove near the end of the shaft
2. Adding a taper at the end of the shaft

**A groove near the end of the shaft**

To avoid jamming, a groove is added to the end of the shaft. At the end, the shaft still has the same diameter as the original shaft, thus the effective length remains the same, but the insertion length is increased compared to the original shaft. The effect is shown in Figure 5.

If $X$ and $Y$ are chosen correctly (see Figure 5 for definition), the insertion length can now be described with:

$$L_{in} = \left[ D_{hole} - 0.5 \cdot (D_{shaft} + D_1) \cdot \cos \alpha \right] / \sin \alpha$$

This groove is very easy and cheap to manufacture. A way to derive $X$ and $Y$ is available on request.
A taper at the end of the shaft

Another way to increase the insertion length is to add a large taper to the end of the shaft. The angle of the taper should be smaller than $\alpha$ and should be large enough to result in an insertion length $L_n > \mu D_{\text{min}}$. Common facets applied at the end of the shaft help position the shaft with respect to the hole but do not influence the jamming behaviour because the angle of the taper is too large to increase the insertion length.

Because $\alpha$ is small, the length of the taper can be too large for small gaps and large shaft diameters. The shaft cannot be used as a functional guide over the length of the taper.

Proposed design methodology

To avoid being surprised by jamming during the assembly stage, the following methodology is proposed:

1. Determine $\alpha_j$.
2. In general, an operator cannot be expected to be able to assemble a series of fittings with $\alpha_j$ when it is smaller than a few degrees, without issues. The designer should realise jamming could become an issue and consider solving the jamming issue and take precautions.
3. When it is decided to create a groove near the end of the shaft (practical solution 1), the dimensions of this groove have to be determined. Start with determining $X$ and $D_i$. Once $X$ and $D_i$ are known, $Y$ can be calculated.
4. Check whether the calculated values for $X$, $Y$ and $D_i$ are realistic.
5. Check whether the new value for $\alpha_j$ is such that jamming is not likely to occur.

Example

The jamming angle is dependent on the diameter and the gap between the hole and shaft. In Figure 7, the angle $\alpha_j$ is shown for varying nominal diameters with fitting H7/g6. The graph shows that for smaller diameters, assembly is relatively easy but for larger diameters, the assembly is more difficult.

Enhancing the minimal gap will increase the angle under which jamming can occur and therefore make it easier to assemble the shaft. This is shown in Figure 8 for varying fittings in the case of a diameter of 100 mm. From these figures, it can be seen that large diameters and small gaps will increase the risk of jamming.

Conclusion

As shown, it is up to the designer to recognise the risk of jamming during the design phase instead of discovering the problem during assembly. If the risk of jamming is recognised, it can be removed in the design thus avoiding any trouble and damage during production/assembly.

Here, the solution has been shown for loose fittings. However, a similar principle can be applied to a press fit, for which the risk of jamming is always present. Assembly of a press fit often results in (unnoticed) damage, leading to different behaviour than designed. Avoiding jamming in a press fit requires a specific solution for each situation. The method to obtain these solutions is available but is beyond the scope of this article.