CONTRIBUTION TO THE OPTIMIZATION OF METAL FLANGE GAS-KETS FOR UNEVEN SURFACE PRESSURE DISTRIBUTION

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1.   Introduction

The demand for higher performance of vehicles, more extensive interior equipment and better crash security paired with the strict environmental standards that are implemented today lead to new lightweight structures for many different components, such as transmission housings.

For the sealing of housing interfaces today metal flange gaskets or liquid sealants are used, e.g. at the interface of transmission cases. A requirement for the leak tightness of these flange gaskets is always a certain minimum surface pressure, which must not fall below a certain value anywhere on the flange. [4]

New structures for lightweight transmission housings, e.g. space-frame housings (as shown in Figure 1), often exhibit a strongly uneven surface pressure distribution on the flange due to the different wall thicknesses or even holes directly over the flange. In extreme cases the pressure between the screw joints can drop to nearly zero (see Figure 2) which makes reliable sealing with standard gaskets difficult.
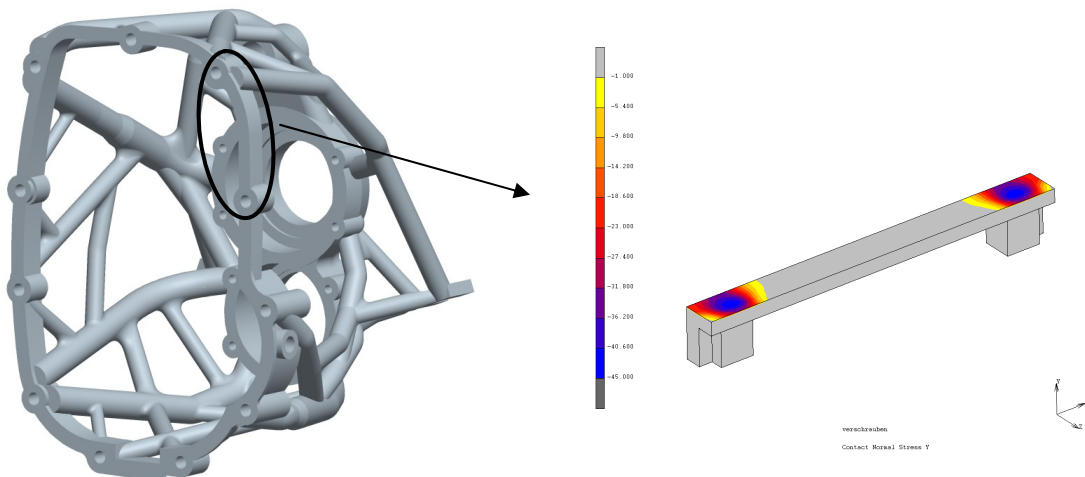

Figure 1: Prototype Space-Frame housing based on topology optimizations

Figure 2: Pressure distribution provided by extremely soft flange (prototype)

On the one hand this can lead to leaks because of too little surface pressure, on the other hand it can lead to the destruction of the sealing because of too much pressure directly under the screws.

The goal of this investigation was the development and optimization of new metal flange gaskets, which can adjust to the uneven surface pressure distribution along the flange. This is achieved through local modifications of the flange geometry.

2.   State of the art

Nowadays the following sealing types are used for sealing of housing interfaces

- *Liquid sealants* – Advantages: one "tube" for every flange geometry; useable with complicated flange geometry, also three-dimensional; application can be automated; high adhesion allows good power and torque transmission.

- *Metal flange gaskets* – Advantages: well defined line pressure through the beads, also with low pressing; high dimensional stability with steady spring-back; can compensate gaps; practically no aging; can be used with soft flanges.

In figure 2 some examples for metal flange gaskets and liquid sealants are shown. [1]

Figure 3: Examples for metal gaskets and liquid sealants

Common metal flange gaskets have a steady cross section geometry across the whole length. The compensation of pressing undulation on the flange is done purely through the available elasticity of the bead. This approach yields good results with non-Space-Frame housings where wall-stiffness never falls below a certain value. For Space-Frame housings these gaskets however don't offer the necessary security reserves for reliable sealing of fluids because of the extreme variations of the pressing standing at disposal in the flange.

In contrast to liquid sealants do metal flange gaskets offer the possibility to locally influence the properties of the gasket. Preliminary investigations [2] have shown that half bead gaskets provide a better adaptation to the flange examined here in contrast to full bead gaskets. Therefore, the further investigations are limited to half bead gaskets.

The poor properties of the sealing flanges (see Figure 1) are to be compensated by means of local modifications of the gaskets' geometry to be able to guarantee a consistently high line pressure and therefore safe sealing under all conditions.

3. Approach

To investigate the sealing mechanism and the influence of different geometrical properties of the gasket a simplified Finite Element model of the flange area of a gear case housing an the gasket was designed (see Figure 4).
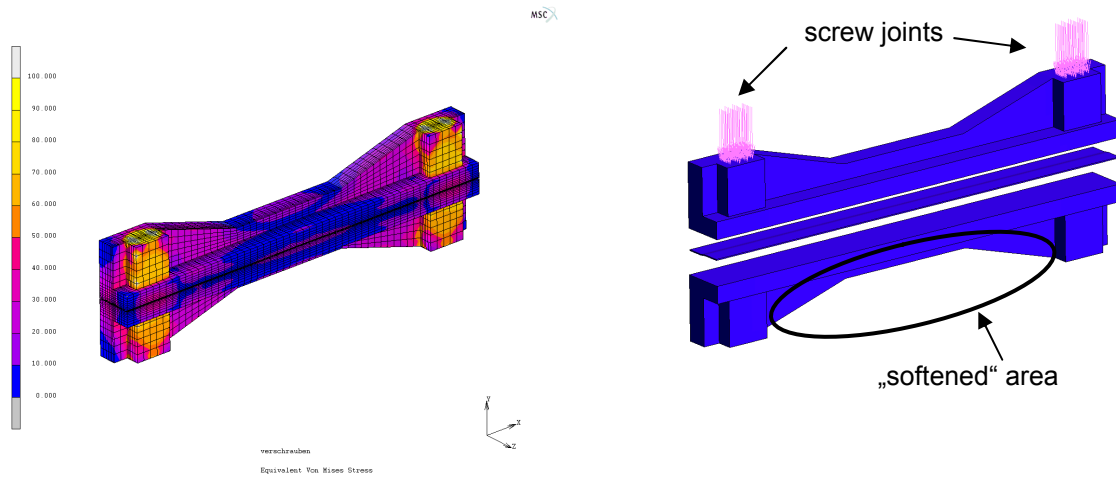

Figure 4: Pictures of the Finite Element Model used for the simulations

The model flange was deliberately "softened" in the middle between the screw joints through removing parts of the wall to receive a relatively large resilience of the flange and therefore an uneven pressure distribution. The material user for the gasket was stainless steel Type 304 which was simulated with elastic-plastic material properties, due to the large deformations the gaskets experienced. [5]

4. Global variation of the parameters

To estimate the influence of each individual geometric parameter of the gasket the parameters were globally varied in a first simulation series [3]. In particular the material strength of the gasket, the broadness of the bead and the height of the bead were modified.

Table 1: the investigated gaskets at a glance

Name of the gasket	Material Strength (D)	Broadness of the bead (B)	Height of the bead (H)
D020	0,20 mm	2,0 mm	0,25 mm
D035	0,35 mm	2,0 mm	0,25 mm
B15	0,25 mm	1,5 mm	0,25 mm
B25	0,25 mm	2,5 mm	0,25 mm
H035	0,25 mm	2,0 mm	0,35 mm
H045	0,25 mm	2,0 mm	0,45 mm
D025_B20_H025 = Reference gasket	0,25 mm	2,0 mm	0,25 mm

Table 1 shows the investigated gasket variants. The gasket labeled as "Reference" displays the comparative basis for all investigated variants. The dimensions used for the material strength of the gasket, the broadness of the bead and the height of the bead correspond to common standard half bead gaskets. The names of the gaskets are composed from the geometrical dimensions, like material strength (D025 means a strength of 0,25mm), broadness of the bead (B20 means a broadness of 2,0mm) as well as height of the bead (H025 means a height of 0,25mm). The names only contain the parameters different from the reference gasket. So B15 means the broadness of the bead is 1,5mm, the other parameters correspond to the reference gasket.

4.1 Variation of the material strength

To investigate the influence of the material strength on the course and the amount of the surface pressure the following gaskets were compared with each other (see Table 2).

Table 2: gaskets with modified material strength

Name of the gasket	Material Strength (D)	Broadness of the bead (B)	Height of the bead (H)
D020	0,20 mm	2,0 mm	0,25 mm
Reference	0,25 mm	2,0 mm	0,25 mm
D035	0,35 mm	2,0 mm	0,25 mm

In figure 2 the pressure curves of the three gaskets were compared. As can be seen in Figure 5, the "pressure" on the flanges was determined through the Normal Stress in Y direction.

First of all one can see that the basic course is very similar. Under the screws a very high pressure develops which drops significantly to the middle of the flange, but never reaches zero.
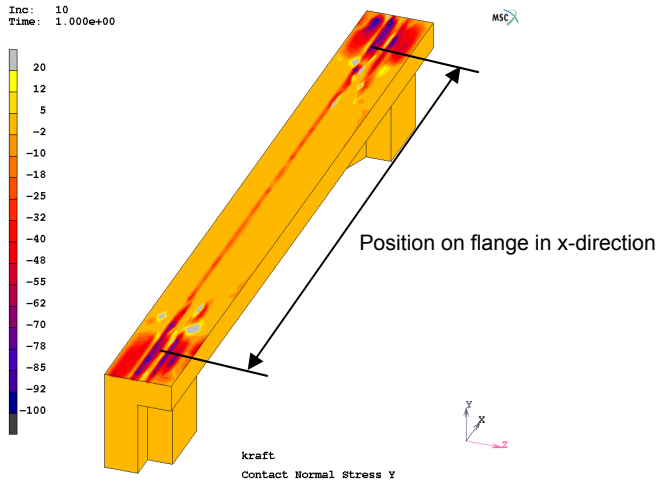

Figure 5: Picture of the Normal Stress on the flange using the reference gasket

The curve of gasket D020 shows clearly that gaskets with a lower material strength in general can only produce a lower lines pressure. This can be explained by the higher degree of plastic deformation that occurs due to the reduced material strength.
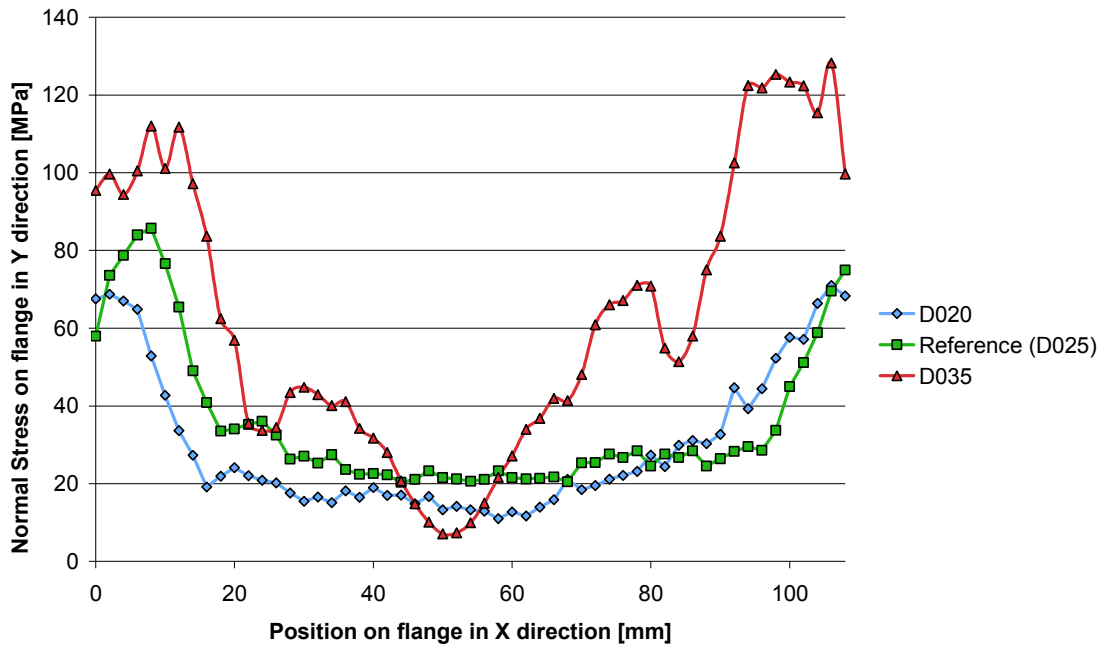
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Figure 6: Pressure curves in dependence of the material strengths (gaskets D020 – Reference – D035)

The curve of gasket D035 shows mostly a higher pressure level than the reference gasket, however strongly drops in the middle of the flange. This can be lead back on the big stiffness of the gasket. As visualized in Figure 7 (see circles) two pressure peaks appear near the two screw joints. By the big pressure the flanges strongly get widened and the gasket cannot follow this large expansion satisfactorily what leads to a pressure minimum in the middle. Figure 8 illustrates this behavior schematically.
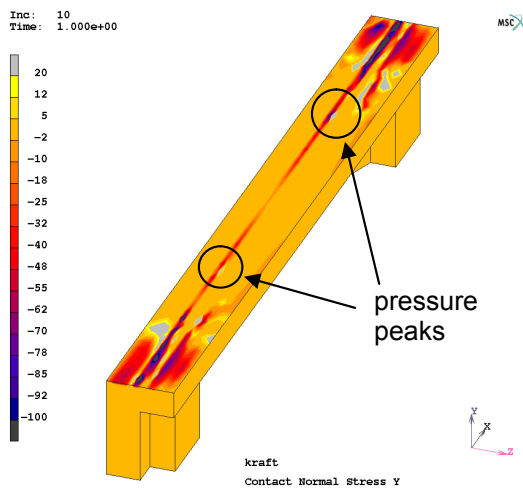

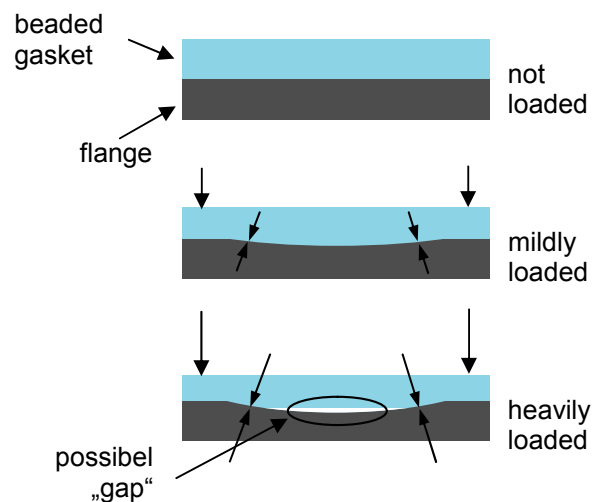Figure 7: lower flange half of the gasket D035

Figure 8: sketch of a two body system consisting of a beaded gasket and a flange

To sum up, one can notice that the obtainable line pressure is reduced by a reduction of the material strength what signifies a deterioration towards the reference gasket. By a rise of the material strength higher line pressures are possible but the added stiffness of the gasket can lead to extreme pressing minima and maxima by overly widening the flanges.

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4.2 Variation of the broadness of the gasket

To investigate the influence of the broadness of the bead on the course and the amount of the surface pressure the following gaskets were compared with each other (see Table 3).

Table 3: gaskets with a modified broadness of the bead

Name of the gasket	Material Strength (D)	Broadness of the bead (B)	Height of the bead (H)
B15	0,25 mm	1,5 mm	0,25 mm
Reference	0,25 mm	2,0 mm	0,25 mm
B25	0,25 mm	2,5 mm	0,25 mm

Figure 9 shows the pressure course of the three gaskets. The basic course is similar again.

Gasket B15 shows a much lower pressure directly under the screw joints (x=5 and x=100) than the reference model, what can be explained by a high plastic deformation of the gasket. In the middle the pressure slightly lies under that of the reference gasket. However B15 shows a more uneven course of the pressure line than the reference model.

The reference model shows a continuous just line as a pressure impression, while with B15 the pressure line shows a slightly uneven course in the middle on account of the strong tilting of the gasket.
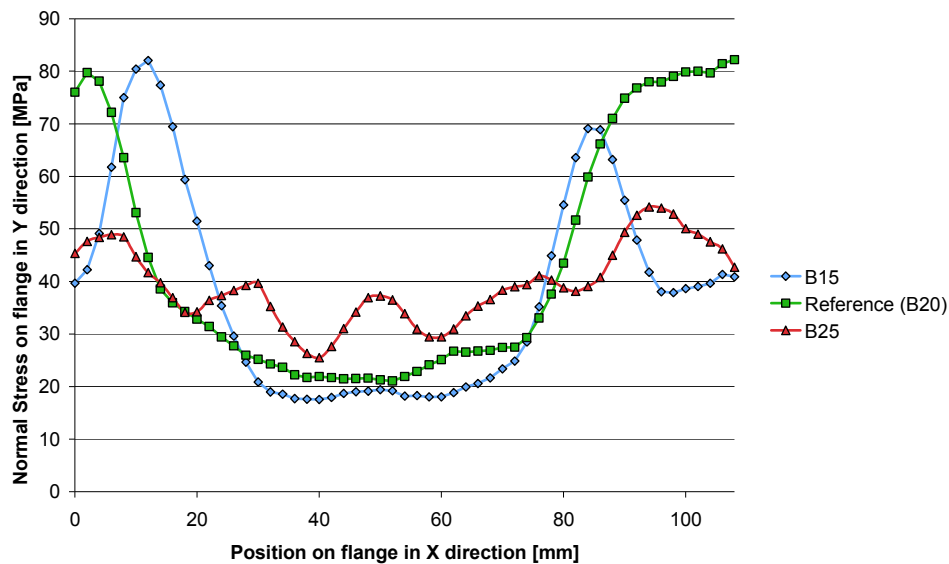

Figure 9: Pressure curves in dependence of the broadness of the bead (gaskets B15 – Reference – B25)

This uneven course can be traced back to the fact that the gasket shows a very steep profile due to the narrow bead. Therefore the gasket becomes strongly tilted under the screw joints, and moves back again to its original position in the middle of the flange. This is also recognizable in the shifted pressure line (see Figure 10).
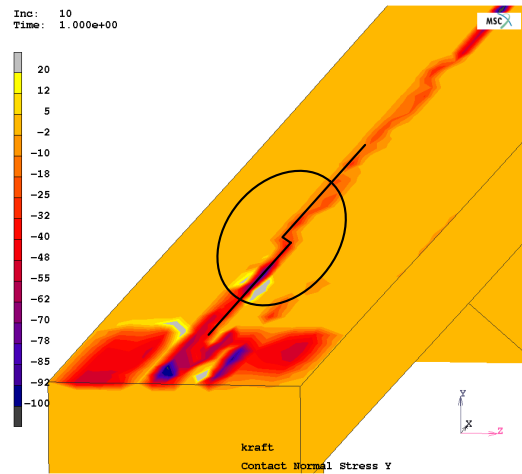
Figure 10: enlarged section of the flange of gasket B15 with indicated pressure course to describe the behavior of the bead

Gasket B25 shows a wavy pressure course which runs in the area from 20 to 60 MPa. The low pressure level under the screw joints, as well as the relatively high pressure in the middle is remarkable. This can be attributed to the reduced spring stiffness of the broader gasket.

This only leads to a slight widening of the flanges in the middle between the screw joints, and consequently to a little more homogeneous pressure distribution in total (see Figure 11). Indeed, the very wavy course of the pressure is not to be considered an optimum.
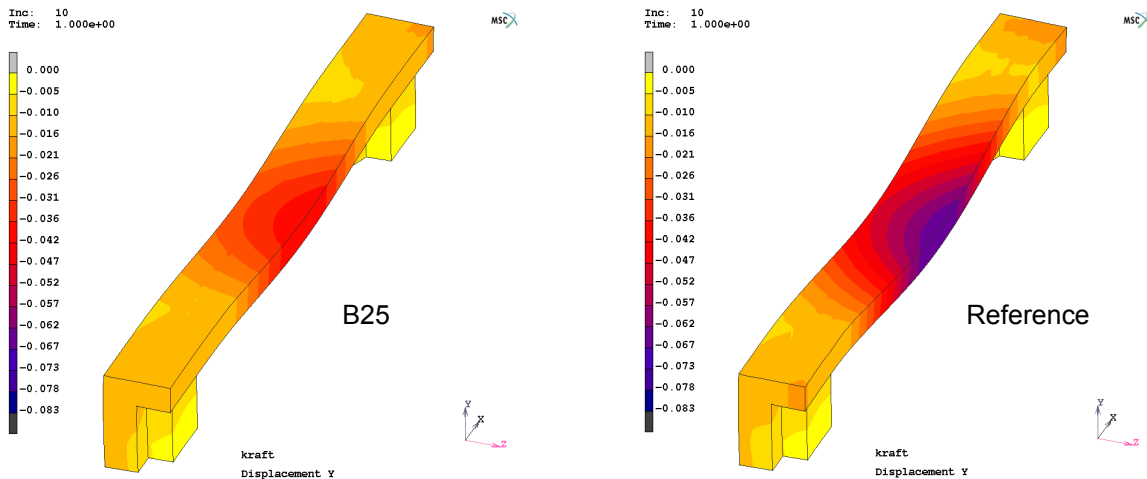

Figure 11: Displacement of the lower flange halves of the gaskets B25 and Reference

To sum up, it can be said that thought a modification of the broadness of the bead the stiffness of the gasket can be selectively modified. A widening of the bead leads to a "softer" gasket, a narrower bead leads to a "harder" gasket. Thereby the loading and the pressure on the flanges can be specifically controlled.

4.3   Variation of the height of the bead

In this chapter the results of the calculations with the gaskets shown in Table 4 are discussed.

Table 4: gaskets with a modified height of the bead

Name of the gasket	Material Strength (D)	Broadness of the bead (B)	Height of the bead (H)
Reference	0,25 mm	2,0 mm	0,25 mm
H035	0,25 mm	2,0 mm	0,35 mm
H045	0,25 mm	2,0 mm	0,45 mm

Figure 12 shows the pressure curves of the three gaskets.

Gasket H35 shows a nearly identical pressure curve compared to the reference gasket but the pressure in the middle area is minimally higher.
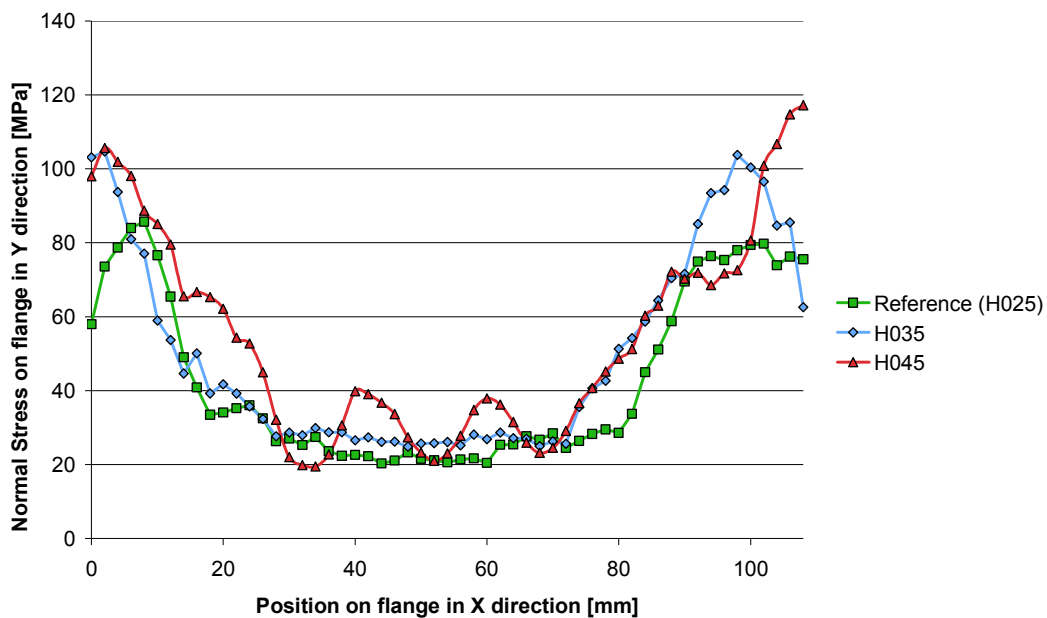

Figure 12: Pressure curves in dependence of the height of the beads (Reference – H035 – H045)

However, H45 shows a very uneven pressure curve with a pressure level mostly above the pressure of the reference gasket. Evidently a strong enlarging of the height of the bead does not necessarily yield a higher pressure.

The gasket that is completely pressed flat under the screw joints produces a shift of the pressure line at x=30mm and x=70mm, see Figure 13. At these locations the gasket tilts back into its original position thus generating an undefined state of pressure. The danger of leakage at these points is big thereby.
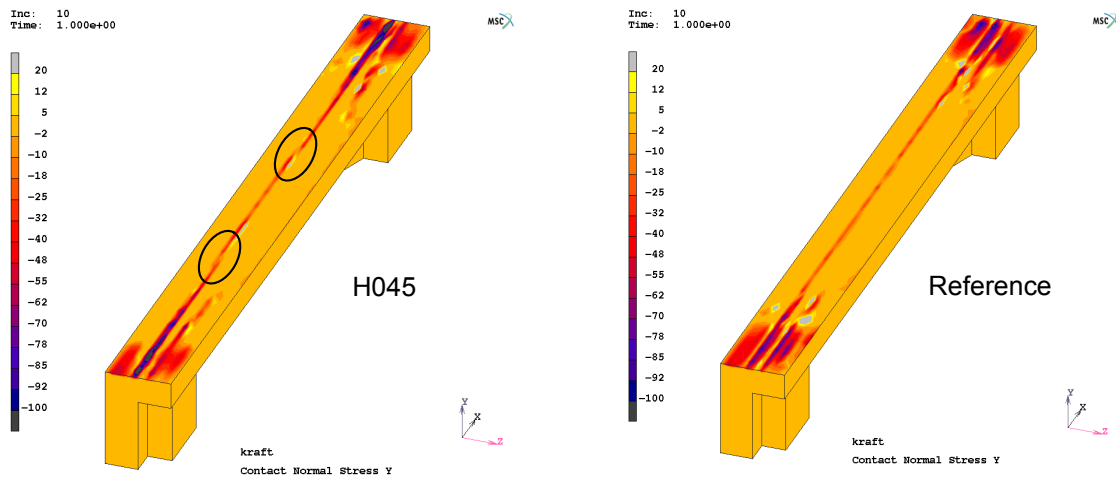
Figure 13: lower flange halves of the gaskets H045 and Reference

4.4 Results

Summarizing, one can ascertain that the pressure distribution strongly depends on the resilience and respectively the widening of the flanges. The widening by the gasket is inevitable to produce the line pressure, indeed one has to pay attention to receive a smooth moderate widening to avoid local pressure maxima and minima.

The stiffness or hardness of the gasket can be selectively influenced by the parameters examined before, and thereby lead to an optimized pressure distribution. In particular the height and width of the bead have a big effect on the characteristics of the pressure line.

5. Locally modified gaskets

As can be seen from the preceding results, when working with extremely soft flanges as they are used in this investigation, the bead of the gasket has to possess a variable stiffness to produce a steady pressure distribution. For this purpose, the gasket must be adapted locally to the flange stiffness.

5.1 Gaskets with a variable width

The gasket can locally be made "softer" or "harder" by a change of the width of the bead. Starting from this consideration the models B20-15 and B20-25 which are displayed in Figure 14 were designed.

Table 5: gaskets with a variable width of the bead

Name of the gasket	Material Strength (D)	Broadness of the bead (B)	Height of the bead (H)
Reference	0,25 mm	2,0 mm	0,25 mm
B20-15	0,25 mm	2,0 - 1,5 mm	0,35 mm
B20-25	0,25 mm	2,0 - 2,5 mm	0,45 mm

Gasket B20-15 shows a diminution of the broadness of the bead from 2,0mm to 1,5mm, gasket B20-25 on the other side shows a widening of the bead from 2,0mm up to 2,5mm.
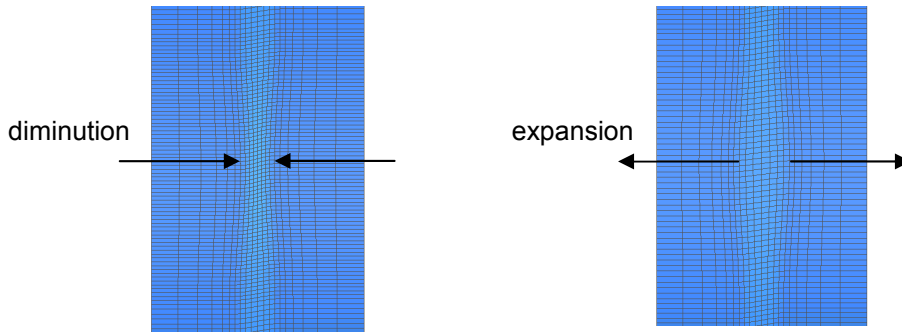
Figure 14: Pictures of the gaskets B20-15 and B20-25

Figure 15 shows that gasket B20-25 generates a much worse pressure distribution in the middle than the reference gasket. This is due to the fact that the gasket B20-25 is softer in the middle than the reference gasket and therefore cannot produce sufficient line pressure.
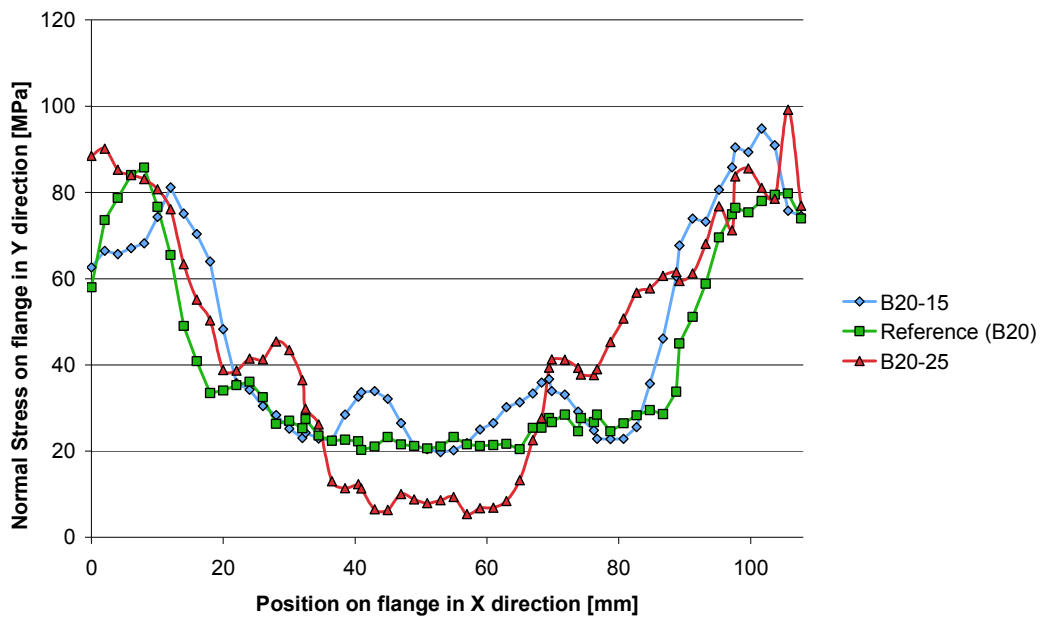

Figure 15: Comparison of the models B20-15, Reference and B20-25

Gasket B20-15 shows better results. Indeed, the pressure curve is much more uneven in the middle compared to the reference model; however two peaks with higher pressure are recognizable. This shows that a reduction of the broadness of the bead, i.e. a "hardening" of the middle area of the gasket, can lead to a better pressure distribution. Although there still exists the need for an optimization because of the uneven pressure.

In an other test row two new gaskets with a material strength of 0,35mm were designed. The farther parameters comply with both above models.

Table 6: gaskets with a variable width of the bead

Name of the gasket	Material Strength (D)	Broadness of the bead (B)	Height of the bead (H)
Reference	0,25 mm	2,0 mm	0,25 mm
D035_B20-15	0,35 mm	2,0 - 1,5 mm	0,35 mm
D035_B20-25	0,35 mm	2,0 - 2,5 mm	0,45 mm

The pressure level of both gaskets exceeds the pressure of the reference gasket due to the larger material strength. Indeed, the pressure level of gasket D035_B20-15 has increased compared to the gasket B20-15, but the curve thereby becomes more uneven. Gasket D035_B20-25 clearly profited from the increase of the material strength. The pressure level now lies about that of the reference gasket; however the overall curve is very uneven.
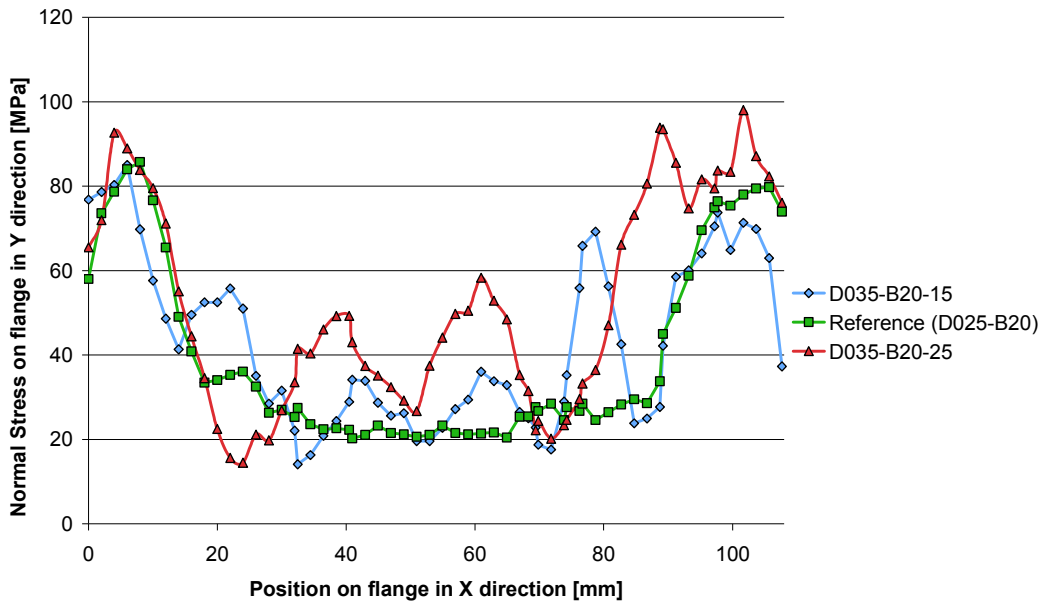

Figure 16: Comparison of the models D035_B15-20, Reference and D035_B20-25

5.2 Gaskets with a variable height

In the further proceedings of this investigation the effect of a variable bead height on the pressure behavior was also checked. At first the height of the bead was modified steadily from the screw joints to the middle to try to prevent the appearance of pressure peaks.

Table 7: gaskets with a variable height of the bead

Name of the gasket	Material Strength (D)	Broadness of the bead (B)	Height of the bead (H)
Reference	0,25 mm	2,0 mm	0,25 mm
H45a	0,25 mm	2,0 - 1,5 mm	0,25 - 0,45 mm
B45b	0,25 mm	2,0 - 2,5 mm	0,25 - 0,45 mm

With model H045a the height of the bead was slowly raised from 0,25mm up to 0,45mm from the screw joints to the middle of the gasket. With model H045b the increase of the height of the bread started later at x=20mm and was therefore more steep.

As can bee seen in Figure 17 the pure increase of the height of the bead generates no significant improvement of the pressure. Also the difference between variant a and b is negligible. However in comparison with gasket D045 (see Figure 12) a much smoother pressure curve is received.
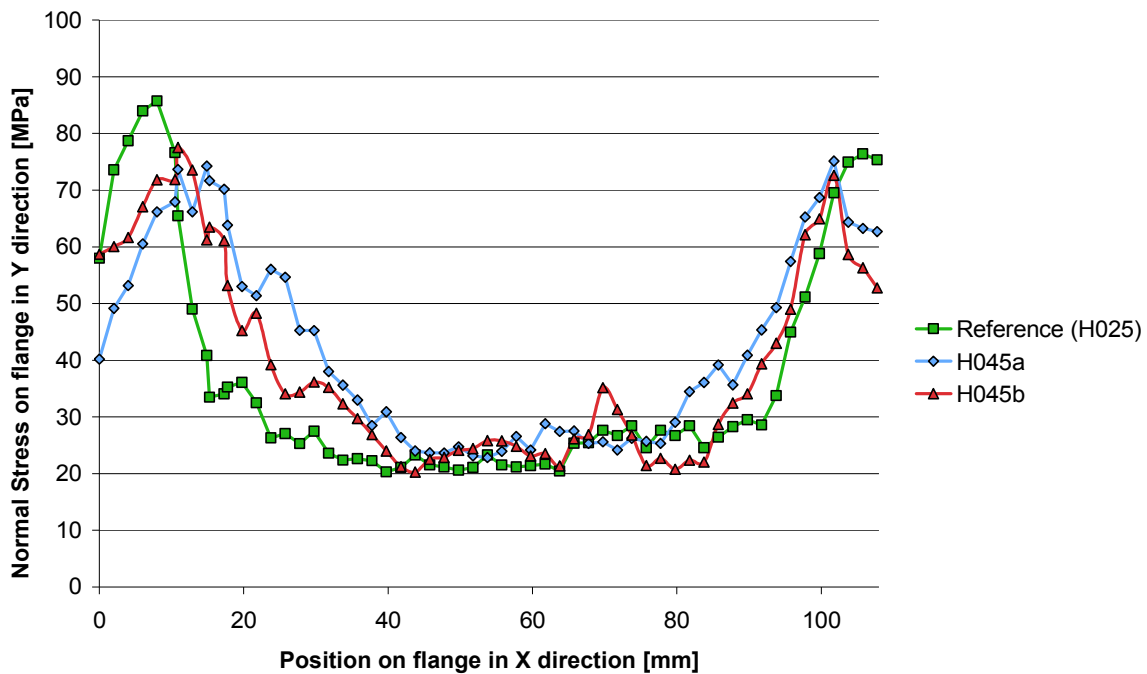

Figure 17: Comparison of the models Reference, H045a and H45b

To obtain an increased pressure two more gaskets with geometry similar to the abovementioned gaskets were designed but the material strength was increased from 0,25mm to 0,35mm. This leads to a general increase in stiffness of the gasket and a higher maximum achievable pressure.

Table 8: gaskets with a variable height of the bead

Name of the gasket	Material Strength (D)	Broadness of the bead (B)	Height of the bead (H)
Reference	0,25 mm	2,0 mm	0,25 mm
D035_H45a	0,35 mm	2,0 - 1,5 mm	0,25 - 0,45 mm
D035_B45b	0,35 mm	2,0 - 2,5 mm	0,25 - 0,45 mm

With model D035_H045a the modulation of the height of the bead starts at position x=14mm and steadily rises from 0,25mm to 0,45mm. Model D035_H045b basically corresponds to D035_H045a with the difference that the modulation of the height only raises slowly at first with a steep incline towards the middle.

Model D035_H045a consistently exhibits a higher pressure than the reference gasket, as can be seen in Figure 18. Model D035_H045b exhibits an even higher pressure but on the other

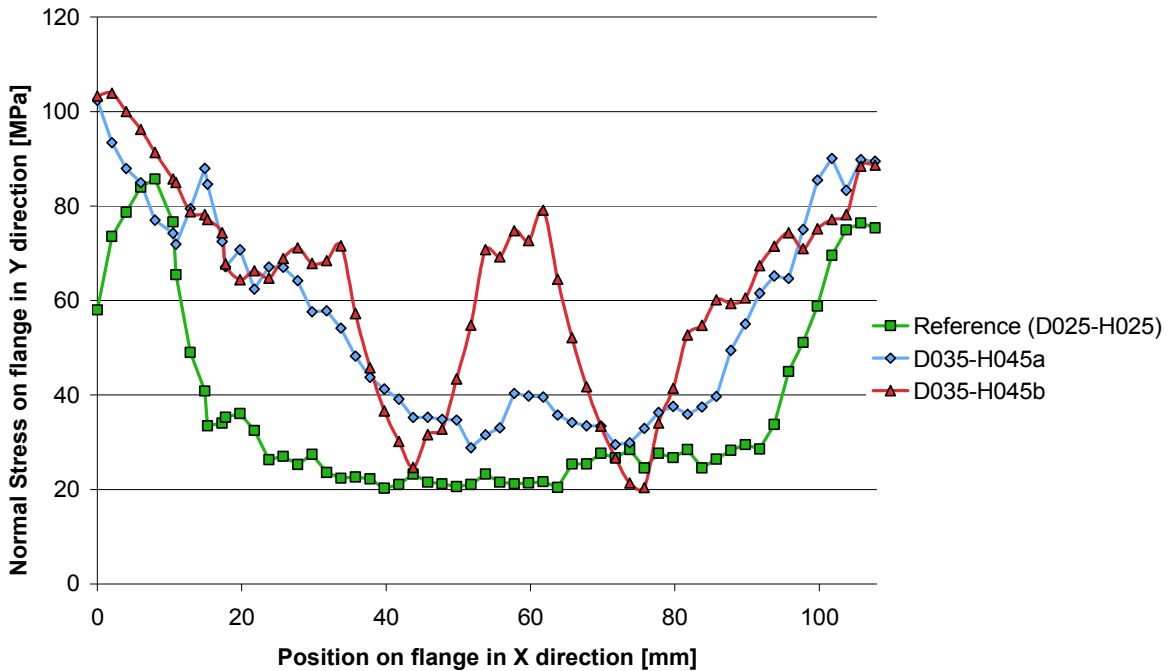hand the curve is also much more uneven that with model D035_H045a and displays a distinctive peak in the middle.

Figure 18: Comparison of the models Reference, D035_H045a and D035_H45b

Nevertheless, the high pressure levels that are reached here are accompanied by high flange deformations as can be seen in Figure 19. Considering this, it is questionable if these gaskets would perform very well in reality due to the very high loads exerted on the flanges.
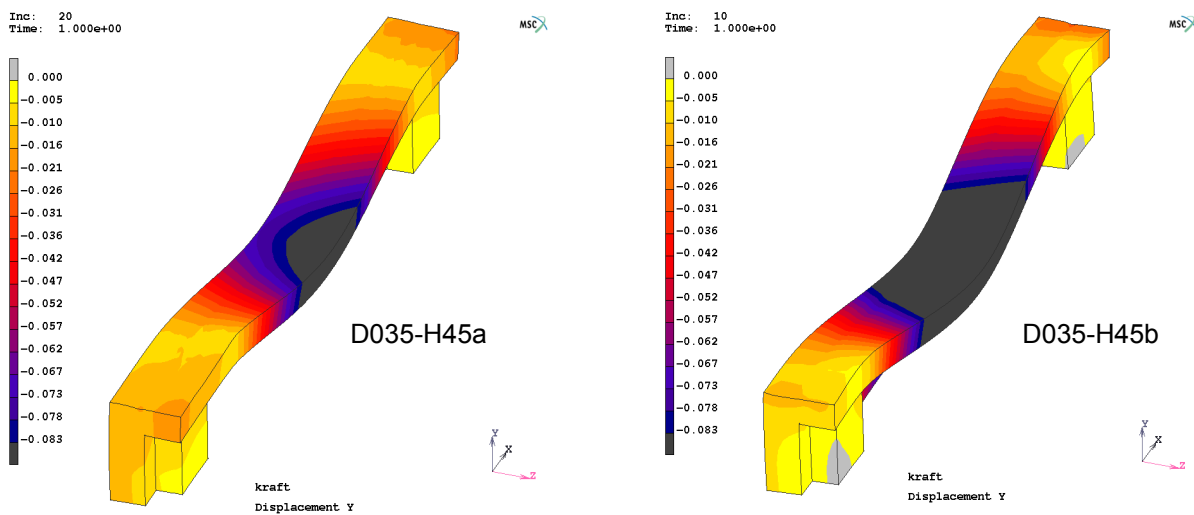

Figure 19: deformation of the lower flange halves of the models D035-H45a and D035-H45b

6. CONCLUSION

In this paper we examined the possibility to enhance the sealing of flanges with strongly uneven pressure distribution, as can be found at space-frame gearbox housings. The approach taken in this paper was to even out the pressure fluctuations on the flange through locally optimized metal flange gaskets and therefore to receive a reliable sealing under all conditions.

First of all we examined the influence of global variations of single geometric parameters on the pressure along the flange. In doing so we could show, that through a global parameter change no satisfying pressure distribution could be achieved. This can le lead back to the high resilience of the flanges used in this investigation.

Furthermore we could show that through locally optimized gaskets that take into account the properties of the flange a higher and smoother pressure level can be received along the whole flange length. An analytical method that delivers the optimal geometry based on the resilience of the flanges and the designated line pressure can now be developed based upon the results of this investigation.

Thus a safe sealing of space frame lightweight construction housings is possible. Further such gaskets also offer the possibility to optimize existing constructions without changing the existing flanges. This gives design engineers much more freedom in the design of new innovative, lightweight housing structures without always having to keep in mind the possibly negative impact on surface pressure in the flange. Therefore this new metal flange gaskets help build lighter more efficient structures.

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