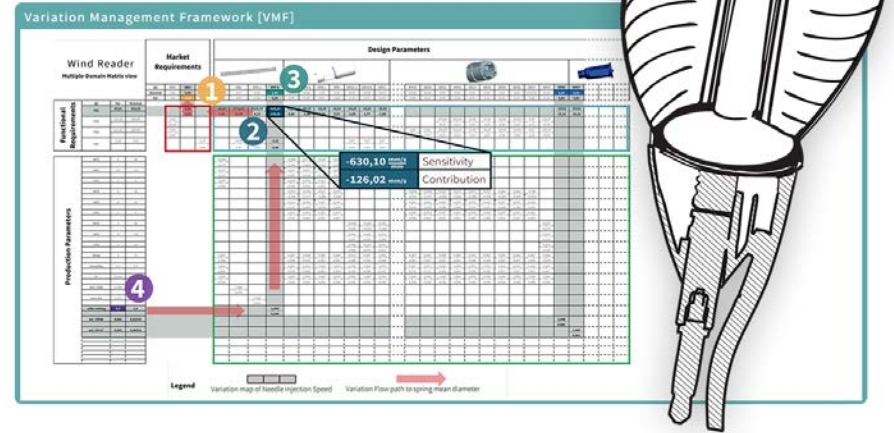


# Robust Design Workshop 2016

## The Variation Management Framework (VMF)

# WORKBOOK



# *Variations are the enemy!*

We can reduce their strength with Robust Design

We can reduce their numbers with Six Sigma

...but we can also defeat our enemies by turning them against one another!

# Agenda

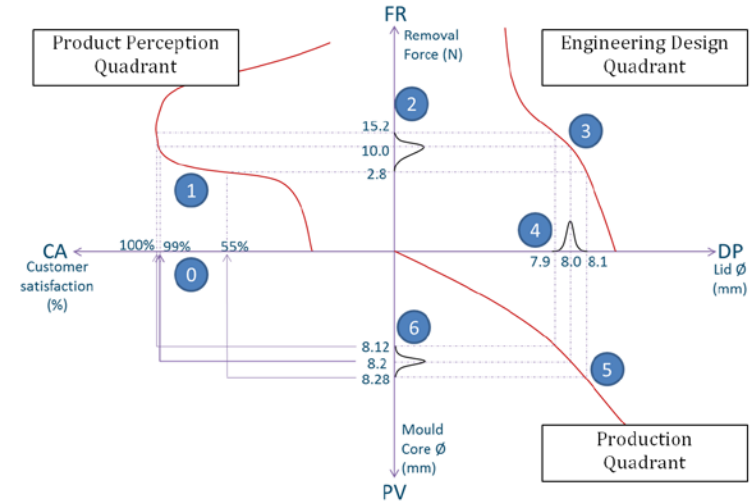
- 13:15 Introduction to workshop
- 13:30 TASK 1: Understanding the design of the case product (10min)
- 13:45 TASK 2: Responding to a production issue without the VMF (10min)
- 14:00 TASK 3: Experimental verification of sensitivity values (20min)  
- 5min Break included in this task
- 14:30 TASK 4: Responding to a production issues with two VMF Quadrants (15min)
- 14:50 TASK 5: Using the VMF to minimize Quality Loss [competition] (15min)
- 15:10 Summary (15min)
- 15:15 END

# About the VMF

The Variation Management Framework (VMF) started as a theoretic framework to describe how variation and sensitivity can be mapped through the production, engineering design and product design domains, give a full account for product quality and robustness.

The VMF was developed at DTU Robust Design Research Group and can be found in the forthcoming publication:

*Howard et al "The Variation Management Framework (VMF) for Robust Design" Journal of Quality Engineering (in review).*

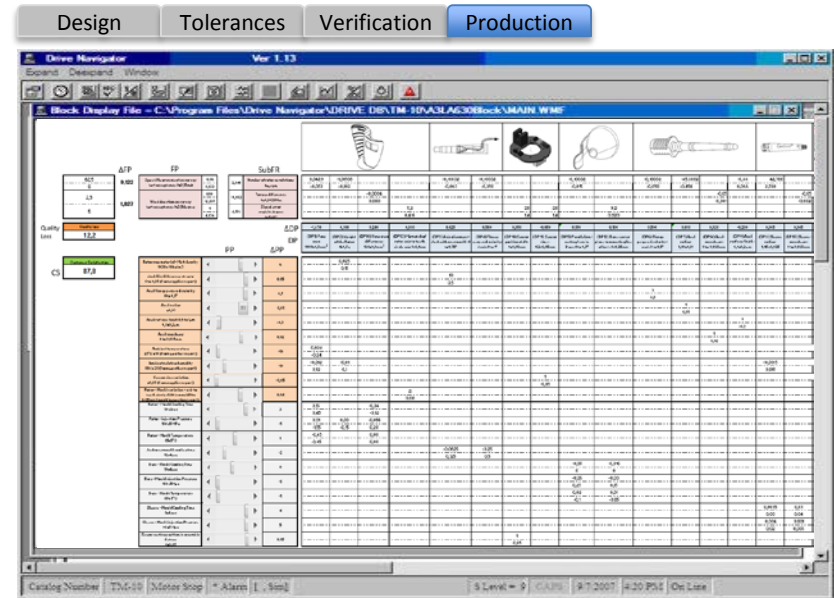


# About the workshop

The DTU research group has been working to operationalise the VMF into a robustness project-management tool.

The tool brings together sensitivity values variation contributions from different simulations and test rigs, providing a common framework where each engineer and specialist can see how their parameters effect the entire product and its performance.

The VMF tool has 4 viewpoints/users – Design, Tolerancing, Verification and Production. This workshop takes the **production viewpoint**, using the VMF to manage product robustness based on incoming measurement data through a case study scenario.



# The VMF Demonstrator

For the purpose of this workshop a simple demonstrator tool has been developed using Microsoft Excel to replicate the VMF production viewpoint. You will be using this for the later exercises.

The data within the demonstrator corresponds to the data within this workbook based on real specifications and some approximations.

Some simplifications of this demonstrator:

- The sensitivity values are linearized taking the sensitivity around the nominal values
- There are no co-variances modelled, so changing the value of one parameter will not effect the sensitivity or contribution of another.
- The contribution values are created by an approximation

For the purpose of the workshop, these limitations can be ignored.



This year's case product...



*The scenarios created for the purpose of the workshop and not reality but aim to be realistic. The majority of the dimensions are based on the actual case files along with the performance criteria. The models and the coefficients used have been simplified to suit the workshop activities and format. While the material cannot be used to replicate the wind reader, it provides a good basis for evaluating the methods put forward.*



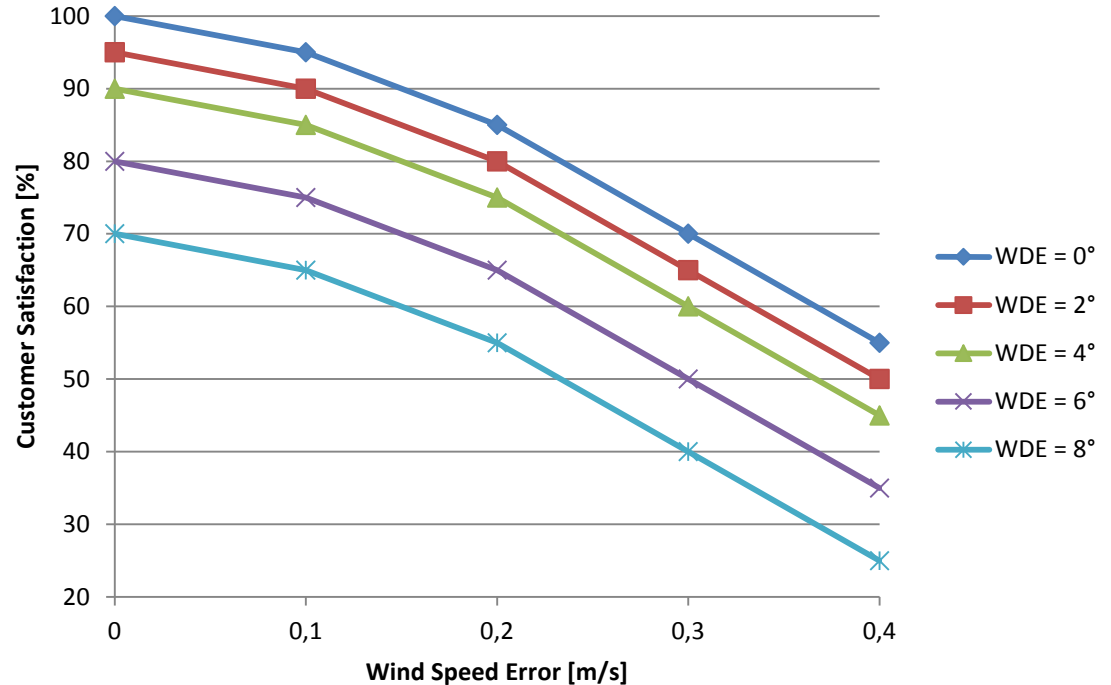
# The Product Key Characteristics...



$\pm 0,22\text{m/s}$  at reference speed of  $5,67\text{m/s}$  (and  $3,5^\circ$  for direction)

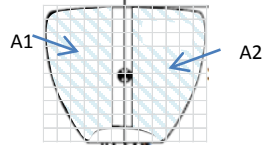
Having conducted a market study, data on how errors in wind direction and wind speed measurements affect customer satisfaction was obtained. In the graph the data has been normalized to a 0-100 customer satisfaction scale

## Customer Satisfaction as a function of Wind Speed Error and Wind Direction Error



**DP1**

Vane area (A)  
1398 ±4,5mm<sup>2</sup>



Total area A1+A2

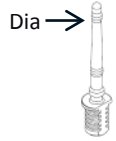
**DP2**

Weight of the Rotor (Rw)  
4±0,5g



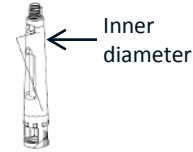
**DP7**

Axel Diameter (Ra)  
1,447±0,01mm



**DP8**

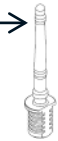
Sleeve Diameters (Rs)  
1,45±0,025



**DP9**

Axel surface finish (Ro<sub>a</sub>)  
0,8 ±0,2 μm

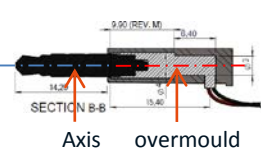
Surface finish at interface



Out sourced

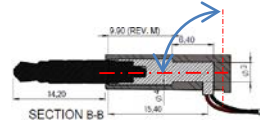
**DP3**

Alignment of Jack with overmould (θ<sub>jm</sub>)  
0 to 0,75°



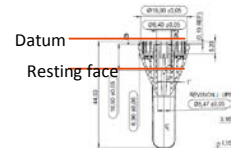
**DP4**

Perpendicularity of Flange with Jack (θ<sub>mf</sub>)  
0 to 1°



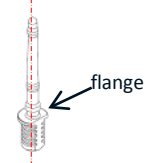
**DP5**

Parallelism of resting face in Base (θ<sub>rb</sub>)  
0 to 0,5°

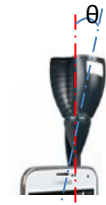


**DP6**

Perpendicularity of Flange with Axel (θ<sub>af</sub>)  
0 to 0,5°

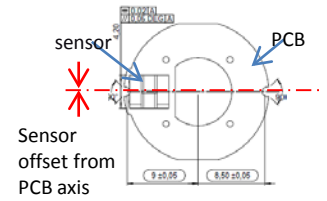


$\theta = \theta_{jm} + \theta_{mf} + \theta_{rb} + \theta_{af}$   
(DP3+Dp4+DP5+DP6)



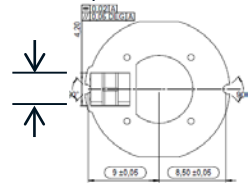
**DP10**

Sensor position (Sp)  
±0,05mm



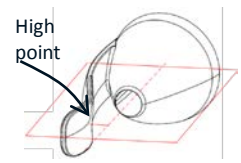
**DP11**

Sensor size (S<sub>s</sub>)  
±0,05mm



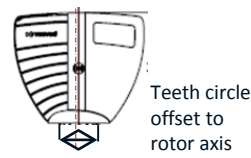
**DP12**

Base center plane to mounting position (M<sub>pp</sub>)  
±0,25mm



**DP13**

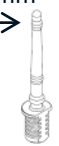
Mismatch - rotor axis to teeth axis (T<sub>co</sub>)  
0,1mm



**DP14**

Axel roundness (A<sub>ro</sub>)  
0,025mm

At interface



**DP15**

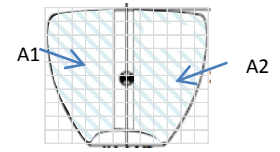
Sleeve roundness (S<sub>ro</sub>)  
0,025mm

At inner diameter interface



**DP16**

Vane area difference (A<sub>d</sub>)  
±0,8mm<sup>2</sup>



Area difference A1-A2

# Transfer functions

## Wind Speed

$$416 \times 10^{-5} A \cos(\theta/15) - 6 \times 10^{-4} R_w^4 - 323,53 \times 10^{-8} R_a A \cos\theta + 163 \times 10^{-3} (R_s^4 - R_a^4) - 30 \times 10^{-2} (R_o a - 0,8)$$

### **Design achievement**

Test conditions: wind speed of  $5,67 \pm 0,22$  m/s (4% of error)  
 (Variation calculation used RSS method)

Note:  $R_a = \text{Axil Dia}/2$   
 $R_s = \text{Sleeve Dia}/2$

## Wind Direction

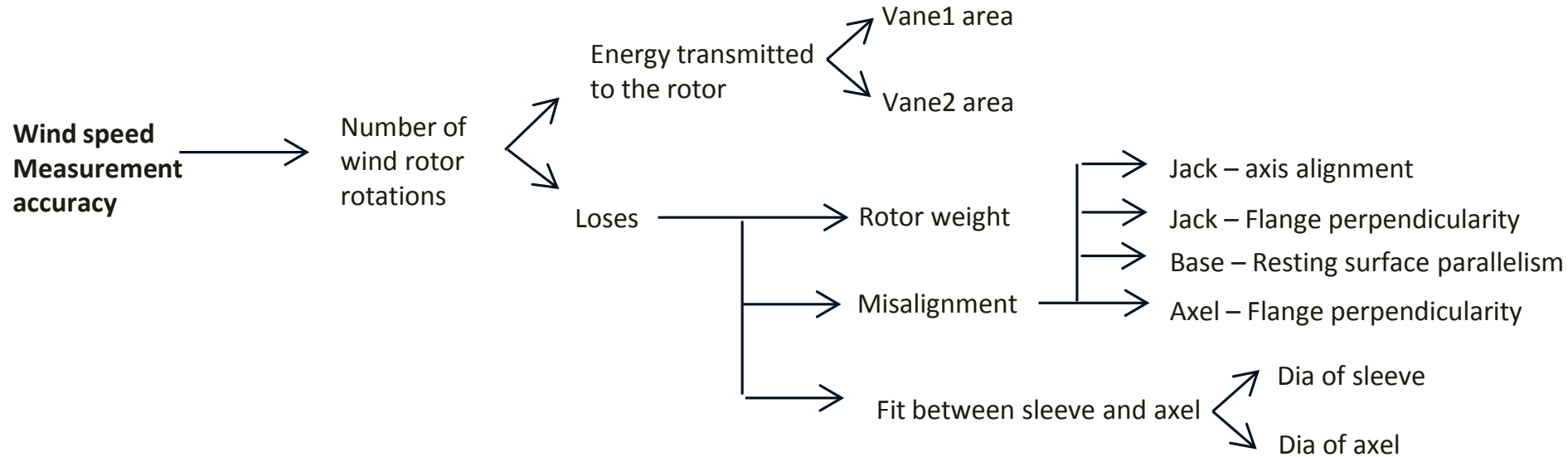
$$0,3 \times (120 - A_d) - 35,7 \times (A_r o + S_r o) + 28 (4,2 + S_p - S_s) + 9,2 M_{pp} + 5,2 T_{co}$$

### **Design achievement**

Test conditions: wind direction  $0 \pm 3,5^\circ$   
 (Variation calculation used RSS method)

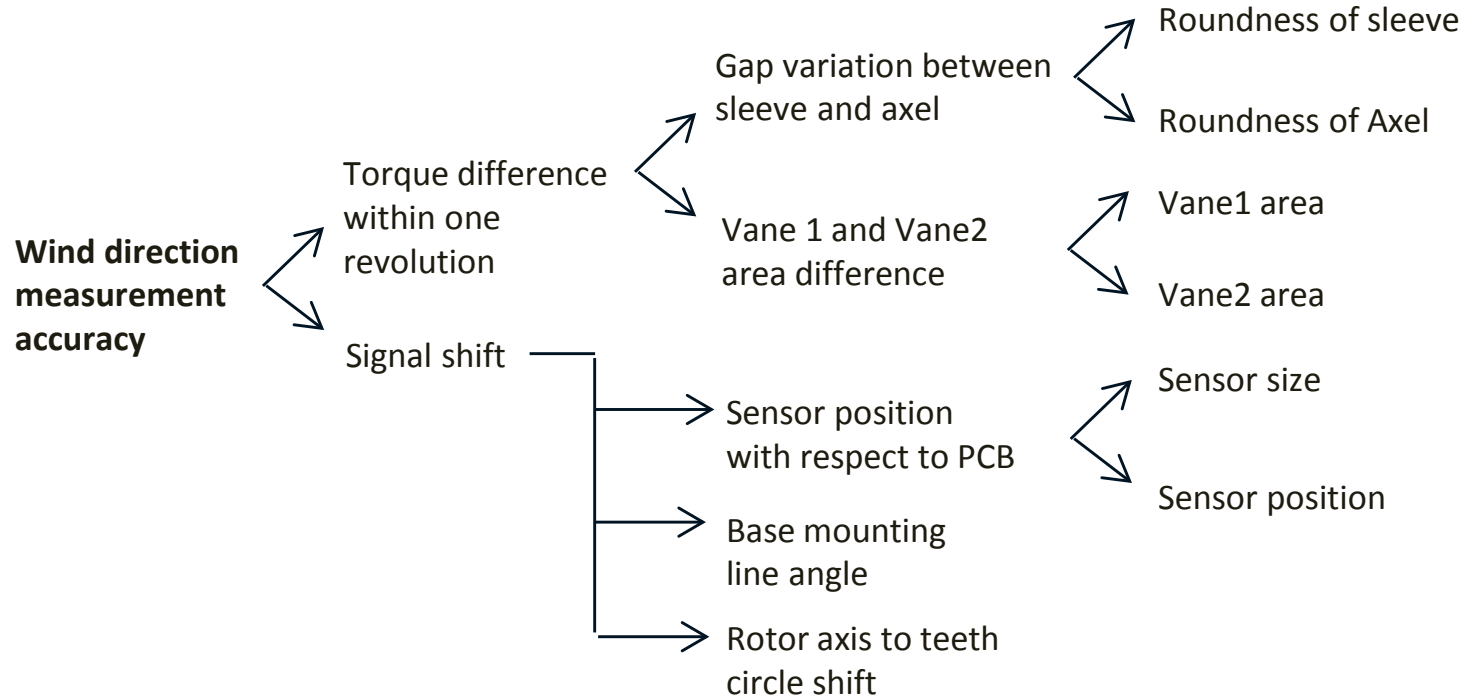
Note: These equations are very crude approximations for the sake of the workshop and are not based on Vaavud's actual transfer functions which are confidential

# Cascading of Functional Requirements Wind Speed



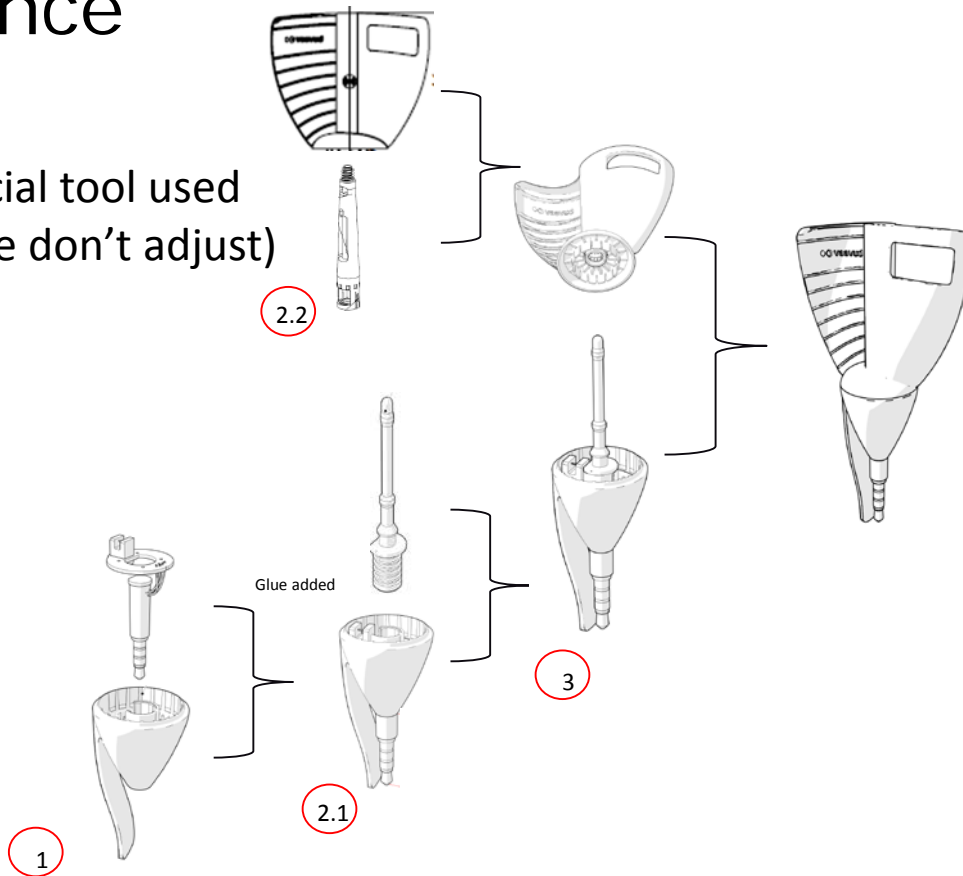
# Cascading of Functional Requirements

## Wind Direction



# Assembly Sequence

Special tool used  
(please don't adjust)



# Production Data

	PP	ΔDP	DP	ΔPP	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	
					(DP1) Vane area 1398±4,5mm <sup>2</sup>	(DP2) Weight of the Rotor 4±0,5g	(DP16) Vane area difference: 120±0,8mm <sup>2</sup>	(DP13) Mismatch of rotor axis to teeth circle axis 0±0,1mm	(DP3) Axis alignment-Jack with over mould: 0 to 0,75°	(DP4) Flange perpendicularity-Jack: 0 to 1°	(DP10) Sensor position shift: 0±0,05mm	(DP5) Parallelism-resting face in Base: 0 to 0,5°	(DP12) Base centre plane to mounting line offset: 0±0,25mm	(DP8) Sleeve Radius: 1,45 ±0,025	(DP15) Sleeve - roundness: 0 to 0,025mm	
Rotor raw material - Melt density 1020 ± 10 kg/m3 (incoming mtl report)	0					0,025										
Jack Dia difference at rests 0 to 0,05 (from supplier report)	0								10							
Ambient temperature 21°C ± 10 (from weather report)	0				0,024											
Ambient relative humidity 80% ± 20 (from weather report)	0				-0,042	-0,025									-0,0045	
Rotor - axis to teeth circle shift in mould 0 to 0,05mm (mould inspection report)	0							2								
Rotor - Mould Cooling Time 10 ±3sec	0				0,15		-0,04									
Rotor - injection Pressure 100 ±5 Mpa	0				0,31	0,06	-0,056									
Rotor - Mould Temperature 85±5°C	0				-0,45		0,08									
Jack over mould cooling time 12±4sec	0								-0,0625	-0,25						
Base - Mould Cooling Time 10±4sec	0											-0,1	0,05			
Base - Mould injection Pressure 100 ±5Mpa	0											-0,01	-0,02			
Base - Mould Temperature 85 ± 5°C	0											-0,05	0,02			
Sleeve - Mould Cooling Time 8±4 sec	0														0,0075	0,01
Sleeve - Mould injection Pressure 90 ±5 Mpa	0														0,004	0,005
Sensor resting position in assembly fixture 0±0,05	0															



# Referencing and using this material

Boorla S.M., Eifler T., Göhler S.M., Pedersen S.N., Bjarklev K., Kronborg N.T., & Howard T.J. (2016) "*The Variation Management Framework (VMF)*" – Robust Design Day 2016 Workshop



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