A summery of Guarantee Fulfillment in Turbine Performance Analyzing 15 years of Turbine Efficiency Measurements

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Abstract
Over the last 15 years (2007 – 2022), Norconsult Norge has measured 140 units using the thermodynamic and the pressure-time method with the purpose of verifying the achievement of the manufacturer's specified guarantees on turbine efficiency. The measurements are performed on both new and upgraded turbines.

The analysis shows that for upgraded turbines the guarantee is fulfilled in 85 % of the times. However, for the turbine manufacturer to achieve the guarantee, the measuring uncertainty has to be taken into consideration 55 % of the times. For new turbines the guarantee is fulfilled in only 60 % of the times (the measuring uncertainty has to be taken into consideration 35 % of the times). Hence, for new turbines, in as much as 40 % of the times, the turbine manufacturer does not fulfill the specified guarantees on the turbine efficiency. There seems to be no major differences between the different turbine manufacturers.

Compared to a similar analysis carried out 15 years ago (ref. [1]) based on measurements performed between 1991 - 2006, in total (both new and upgraded turbines) the number of times the guarantee is fulfilled without including the measuring uncertainty is fairly constant. For the two time periods analyzed, the figure is about 30 %. However, one positive trend is that, in total, the number of times the guarantees are not fulfilled is reduced. The figure is almost halved from about 40 % in 1991-2006 to about 20 % in 2007-2022. This means that more projects (especially upgrade projects) have been moved into the category where the guarantees are fulfilled including the measuring uncertainty.

1 Introduction
Over the last 15 years (2007 – 2022), Norconsult Norge has measured 140 units using the thermodynamic and the pressure-time method with the purpose of verifying the achievement of the manufacturer's specified guarantees on turbine efficiency. The measurements are performed on both new and upgraded turbines.

This paper discusses various topics, including the percentage of guarantees fulfilled and the impact of measurement uncertainty on these fulfillments.

This analysis was also carried out 15 years ago based on measurements performed between 1991 - 2006 (ref. [1]), and the two time periods are compared, investigating the presence of any trends within the data.

2 Input basis
The input basis is data from measurements performed on new and upgraded turbines where a guarantee for the turbine efficiency is stated in the Contract. By new turbines it is understood that the whole unit is new; the design is optimized so that the components are hydraulically fit to each other in the best possible way. Upgraded turbines are turbines who have been upgraded for instance by a new runner of more resent hydraulic design, new guide vanes/injectors etc.

The survey includes units designed both by world leading companies and more local turbine manufacturers.

2.1 Time period 1991-2006
For the original survey, the characteristics of the input data were as following:

- Total number of units: 101
- Number of new units: 18 (7 Francis turbines, 11 Pelton turbines)
- Number of upgraded units: 83 (31 Francis turbines, 52 Pelton turbines)
- Measurement method: Thermodynamic method

2.2 Time period 2007-2022

For the new survey the following characteristics of the input data are:

- Total number of units: 140
- Number of new units: 42 (24 Francis turbines, 18 Pelton turbines)
- Number of upgraded units: 98 (63 Francis turbines, 35 Pelton turbines)
- Rated head range: 50 – 950 m
- Rated output range: 2.18 – 350 MW
- Measurement method: Thermodynamic method (136) and pressure-time method (4)

The rated head and the rated output for the units measured, are also evident from Figure 1.

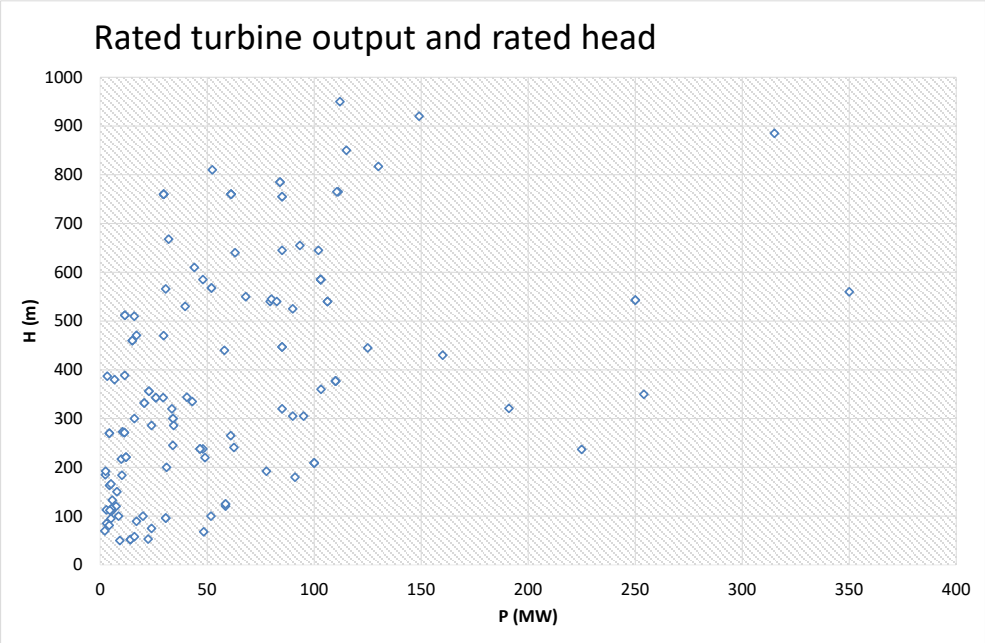

Figure 1 Rated turbine output and rated head for units measured 2007-2022

3 Comparison with guarantees

When comparing the test results with the guarantees, the results are divided into three categories:

- Test results where the measured efficiency exceeds the guarantee (guarantees fulfilled)
- Test results where the measured efficiency is lower than the guarantee but within the total measurement uncertainty (guarantees fulfilled including measuring uncertainty)
- Test results where the measured efficiency is lower than the guarantee but outside the total measurement uncertainty (guarantees not fulfilled)

These categories are shown graphically in Figure 2 - Figure 4.

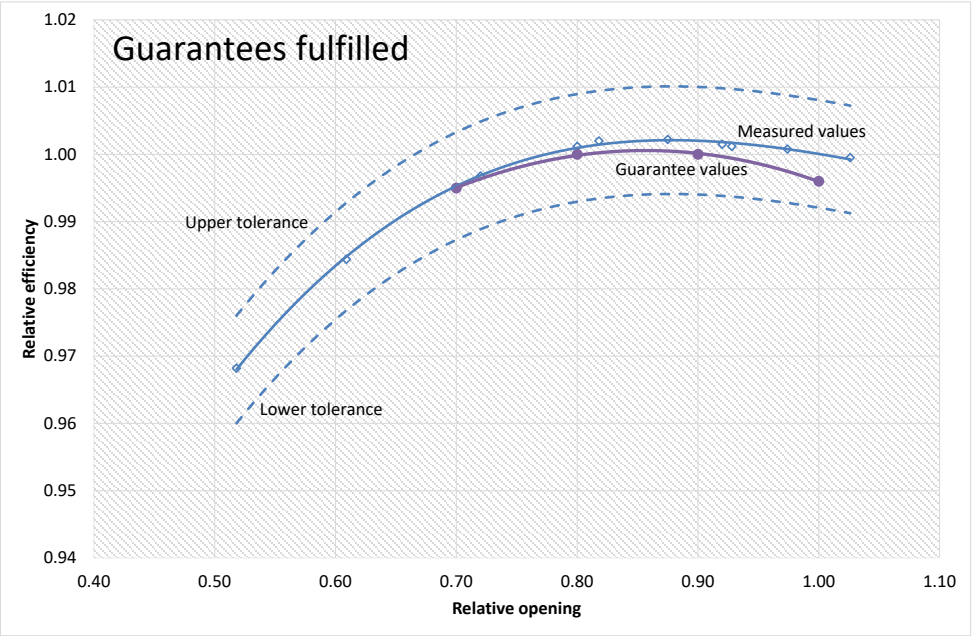

Figure 2 Measured efficiency exceeds the guarantee (guarantees fulfilled)

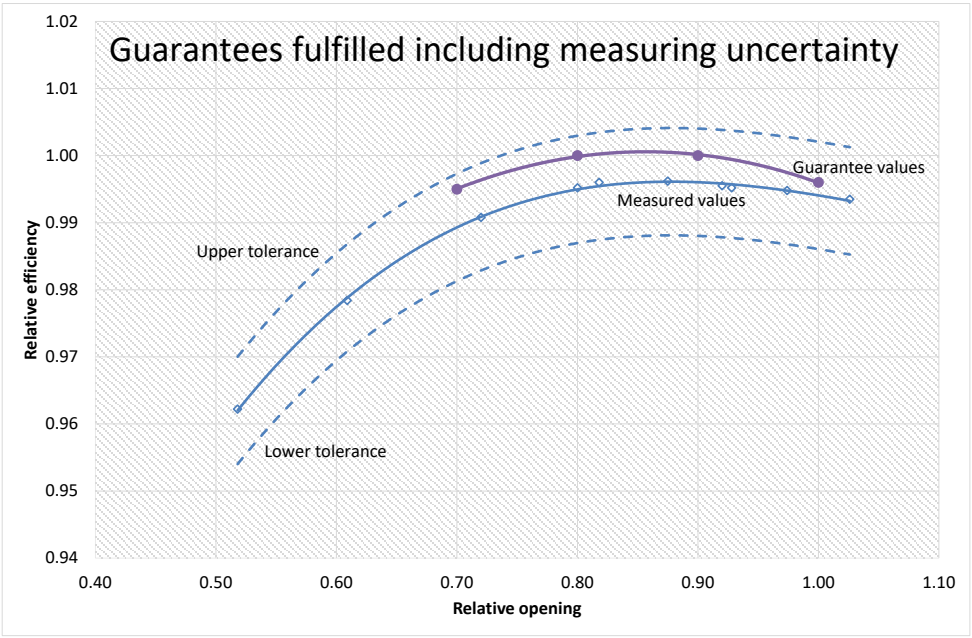

Figure 3 Measured efficiency is lower than the guarantee but within the total measurement uncertainty (guarantees fulfilled including measuring uncertainty)

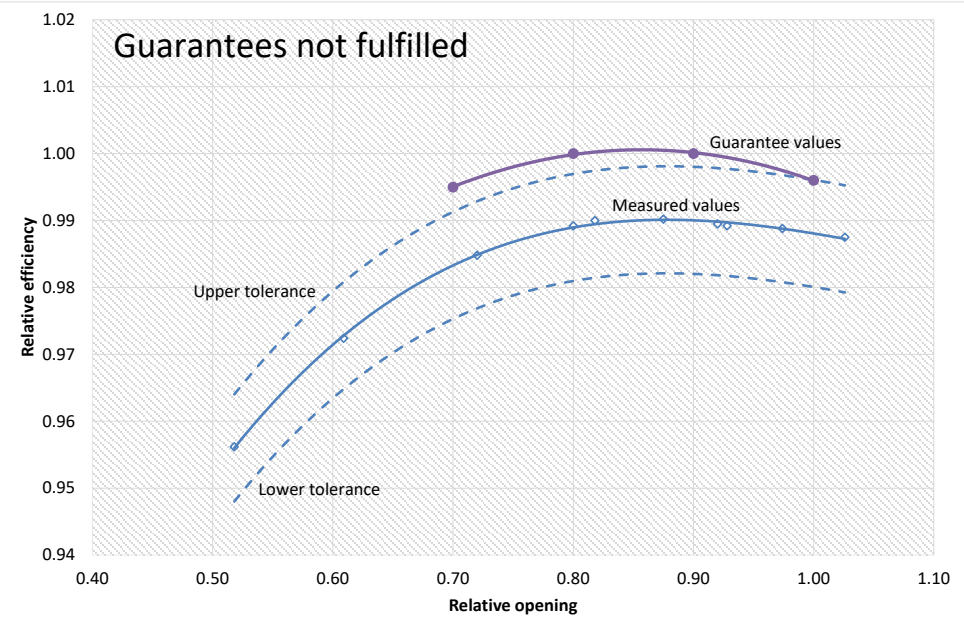

Figure 4 Measured efficiency is lower than the guarantee but outside the total measurement uncertainty (guarantees not fulfilled)

For this survey the comparison with the guarantee is based on the weighted average efficiency (WAE). The WAE is calculated according to:

$$WAE = \sum_{i=1}^{n} w_i \cdot \eta_i$$

where n = number of weighing points
w_i = weighing factor at point i
η_i = efficiency at point i

When the WAE is greater than the guaranteed value, the guarantee is fulfilled. When the WAE is below the guaranteed value, but the WAE plus the total measurement uncertainty (upper tolerance) is grater than the guaranteed value, the guarantee is fulfilled including the measuring uncertainty. When the WAE is below the guaranteed value and the WAE plus the total measurement uncertainty (upper tolerance) still is below the guaranteed value, the guarantee is not fulfilled.

4 Results and analysis

4.1 Time period 2007-2022

4.1.1 New units

As can be seen from Figure 5, for about 40 % of the tests performed, the guarantee is not fulfilled. The figure is almost the same for both Francis and Pelton turbines (the number of horizontal Pelton turbines is too small to be statistically true). For the rest of the tests performed the guarantee is fulfilled; either with use of the measuring uncertainty (ca. 35 %) or without (ca. 25 %).

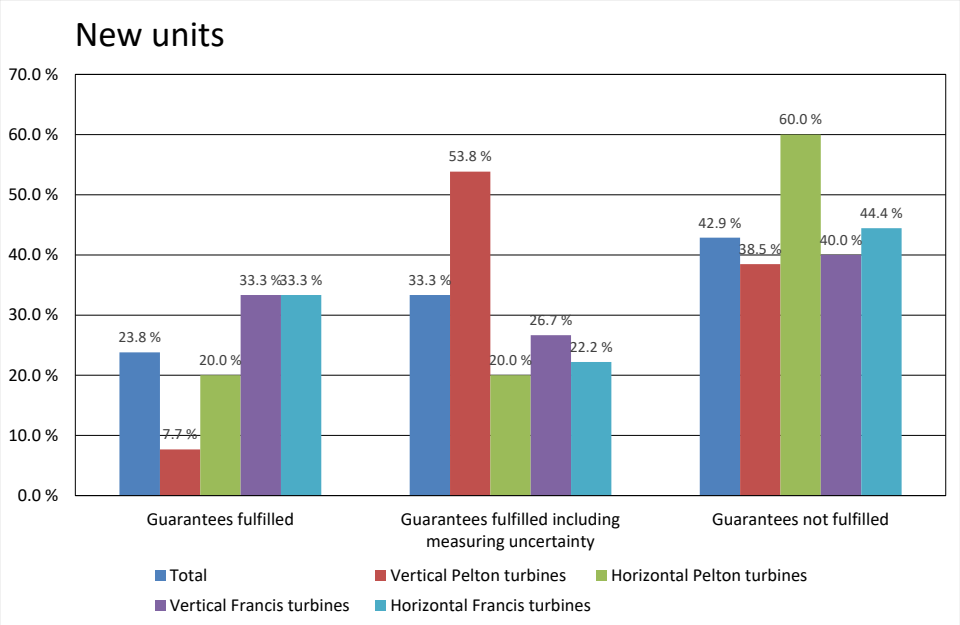

Figure 5 Distribution new units

4.1.2 *Upgraded units*

As can be seen from Figure 6, upgrade projects have a better success rate than new projects. The guarantee is not fulfilled in about 15 % of the tests performed. However, for horizontal Francis turbines the figure is as high as 40 %. For the rest of the tests performed the guarantee is fulfilled; either with use of the measuring uncertainty (ca. 55 %) or without (ca. 30 %).

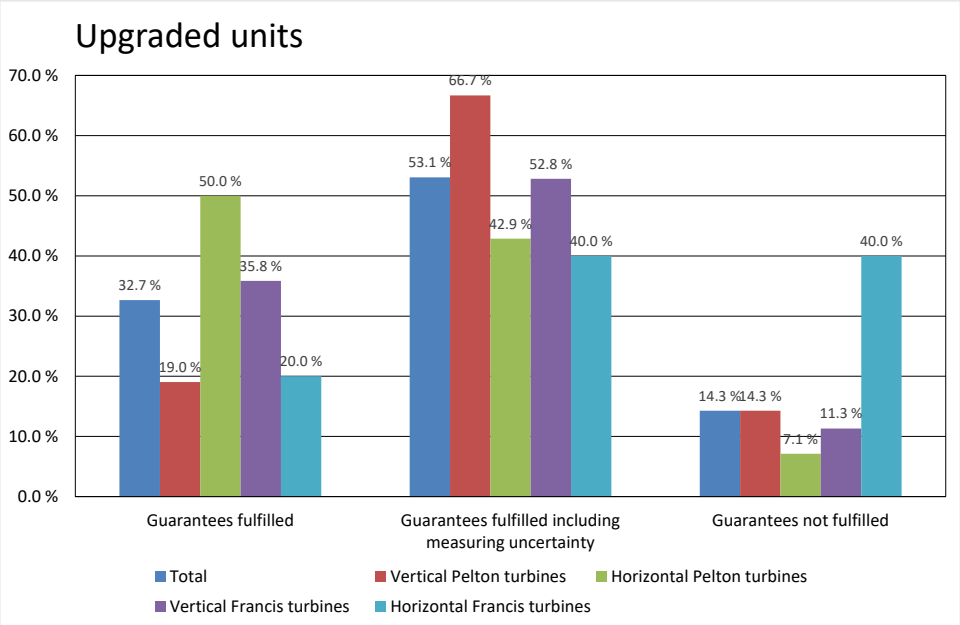

Figure 6 Distribution upgraded units

4.1.3 *Both new and upgraded units*

As can be seen from Figure 7, in total (both new and upgraded units) the guarantee is not fulfilled in about 25 % of the tests performed. For the rest of the tests the guarantee is fulfilled; either with use of the measuring uncertainty (ca. 45 %) or without (ca. 30 %).

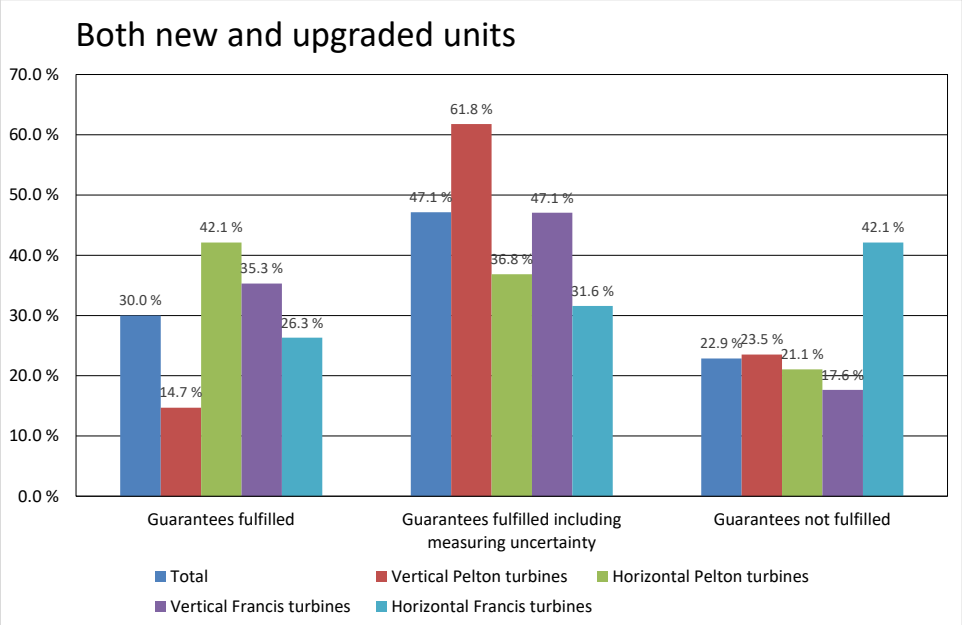

Figure 7 Distribution both new and upgraded units

4.2 Comparison with the 1991–2006 time period

4.2.1 New units

As can be seen from Figure 8, the number of tests performed that do not fulfill the guarantees for new units is considerably reduced. A reduction of 30 %pp (from 77.8 % to 42.9 %) is registered.

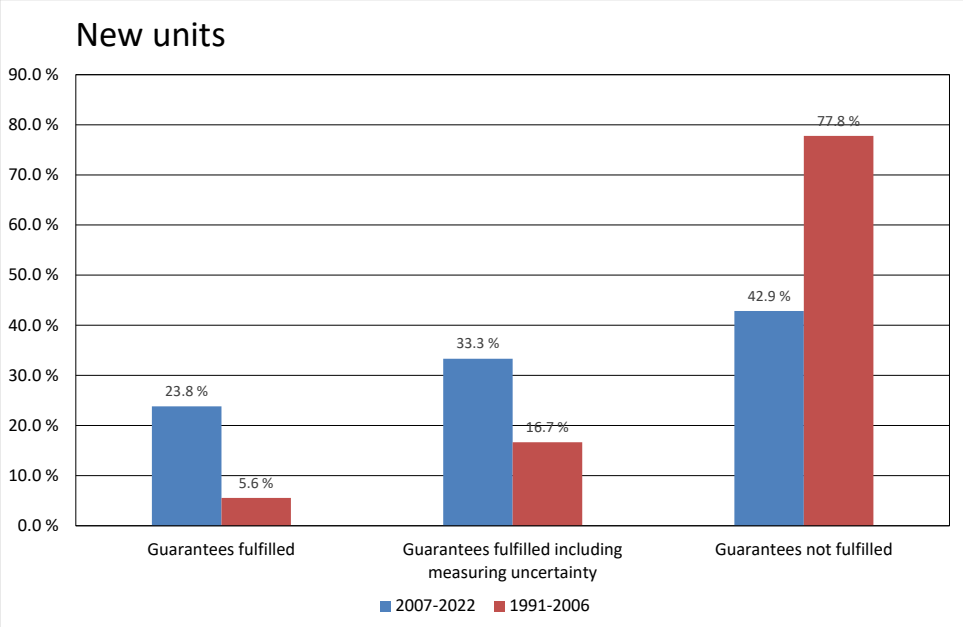

Figure 8 Comparison new units

4.2.2 Upgraded units

As can be seen from Figure 9, the number of tests performed that do not fulfill the guarantees is reduced for upgraded units as well. The reduction is 20 %pp (from 34.9 % to 14.3 %). Pelton turbines has a greater improvement rate than Francis turbines (see Figure 10). Tests where the guarantees are fulfilled without including the measuring uncertainty, is at the same level as before.

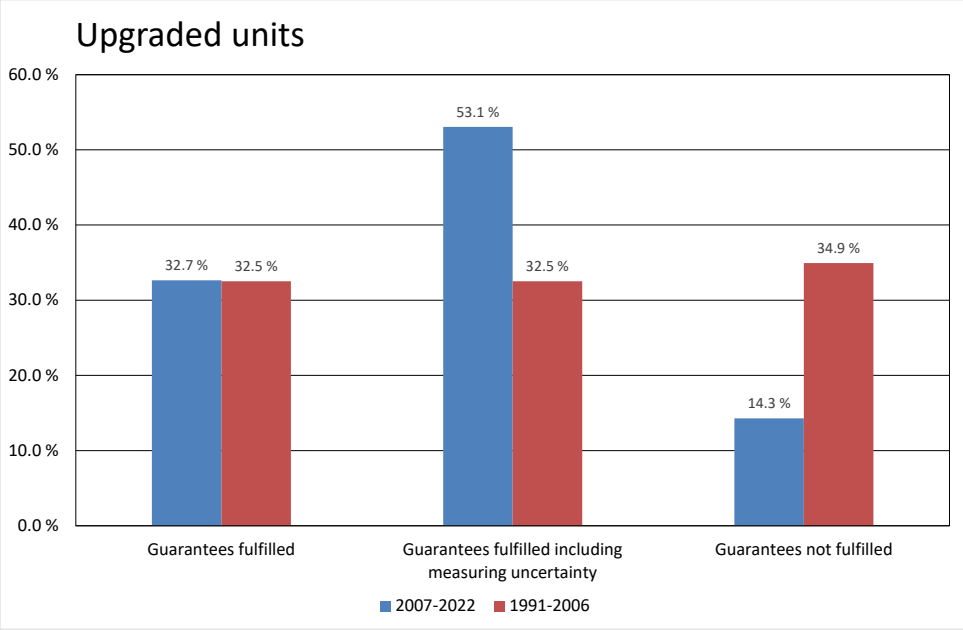

Figure 9 Comparison upgraded units

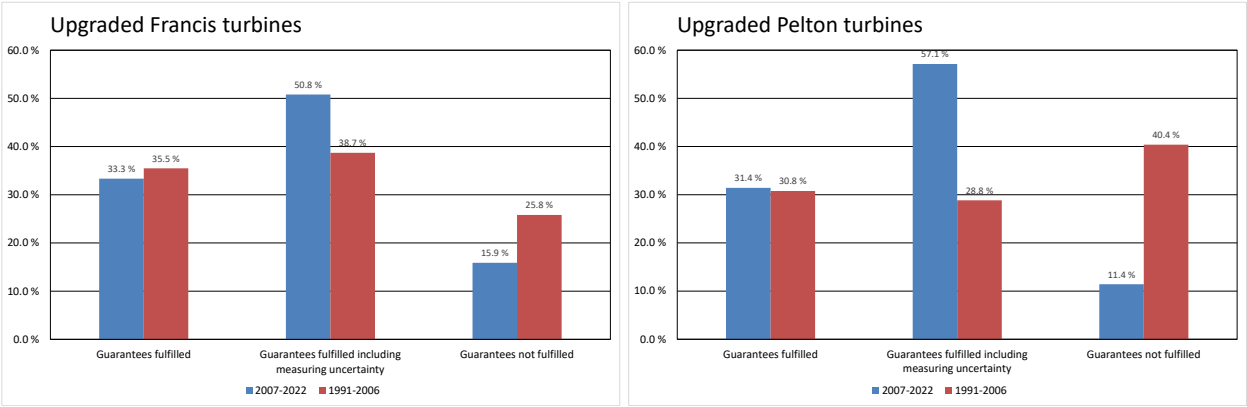

Figure 10 Comparison upgraded units, Francis and Pelton units

4.2.3 *Both new and upgraded units*

As can be seen from Figure 11, in total (both new and upgraded units) the number of tests performed that do not fulfill the guarantees is reduced for the 2007-2022 period compared to the 1991-2006 period. The reduction is 20 %pp (from 42.6 % to 22.9 %).

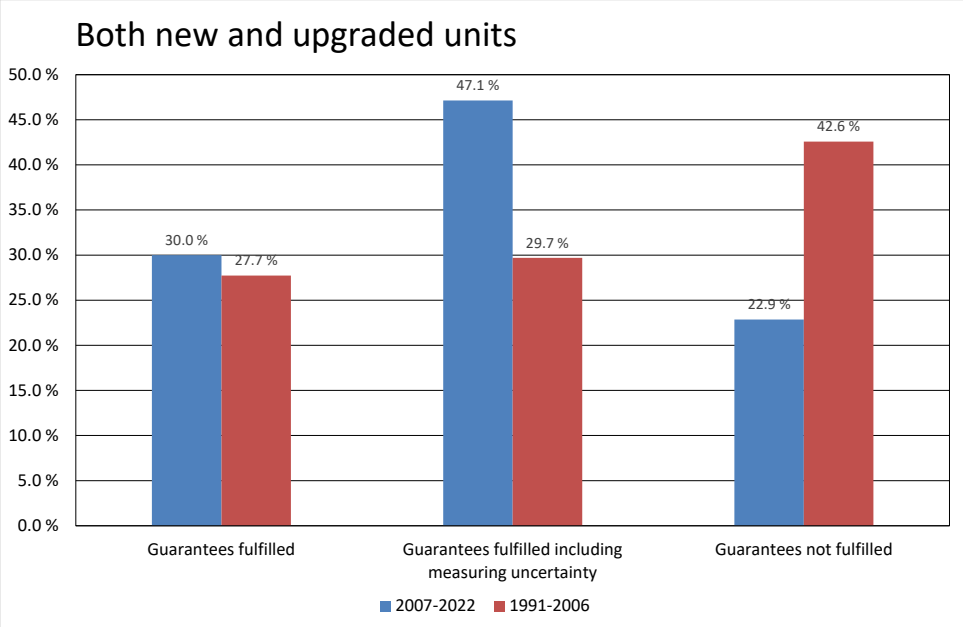

Figure 11 Comparison both new and upgraded units

5 Conclusion/Discussion

In total the number of tests performed where the guaranteed value is exceeded (measuring uncertainty not included) is more or less the same for the two time periods analysed (about 30 %).

It is however gratifying to notice that the part of the number of tests performed that do not fulfill the guarantees is reduced. The reduction is about 20 %pp. More projects have been moved into the category where the guarantees are fulfilled including the measuring uncertainty. Reasons for this finding may arise due to for instance:

- new and improved design tools (computer software)
- better understanding and more experience of the design tools used
- improved turbine models
- improved and more accurate production/manufacture methods

A displeasing reading/result is the number of tests performed on new units that do still not fulfill the guarantee. Based on this analysis the value is as high as 40 %. The figure is almost the same for both Francis and Pelton turbines, both horizontal and vertical configuration. There also seems to be no major differences between the different turbine manufacturers. Conditions that may affect this figure can for instance be:

- commercial factors; for instance for a turbine manufacturer to be awarded the project, a high turbine efficiency guarantee is usually needed
- the step-up formulas used for transposing the turbine efficiency from model to prototype are too optimistic
- non scalable losses are estimated too small
- the feedback from prototype measurements is limited
- production/manufacture methods used

6 References

[1] *Erik Bøkko/E-CO Vannkraft – «Turbinvirkningsgrad, garantert og målt. Statistisk resultatoversikt for en serie termodynamiske virkningsgradsmålinger av nye og nyreviderte turbiner», 2006-12-04*
(Erik Bøkko/E-CO Vannkraft – «Turbine efficiencies, guaranteed versus measured values. A statistical overview for a series of thermodynamic measurements performed on new and upgraded turbines», 2006-12-04)