Discharge Measurement with OTT Can-Bus-Current-Meter
at
Hydro Power Station Limmritz

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1. General

The measurement of discharges and heads as well as electrical real power of the single hydroelectric generating sets have been carried out on October 8^{th} and 9^{th}, 2001.

The Institute for Hydraulic Engineering (Institut f. Wasserbau- IWS) of the University in Stuttgart and the company OTT MESSTECHNIK in Kempten were responsible for the discharge and head measurements.

2. Measurement System and Data Acquisition

Especially important for the determination of efficiency are the determination of discharge by means of flow velocity measurements, the head determination and the monitoring of power and electrotechnical variables (e.g. cosΦ). Moreover, details about the water consistency, the system relevant mechanical engineering data and electrotechnical data, as well as the technical data of the turbine manufacturer are required.

In the following, a short overview of the measurement installations and requirements is given.

2.1. Discharge

The velocity was monitored by a measurement fence supplied by OTT MESSTECHNIK. This fence consists of 30 current meters, five current meters of which are mounted at defined intervals on each of the totally six vertical aluminium rods. This measurement fence with the six vertical aluminium rods, equipped with Can-Bus-Current Meters (see Image (1)) was mounted in the four turbine inflow channels in one after the other, the moveable fixing elements at the bottom and at the ceiling allowing for a fine adjustment of the horizontal intervals between the rods.

Image (1): Can-Bus-Current Meter and Can-Bus-Current Meter mounted on an aluminium rod ready for installation.

The current meters were positioned in the fence consisting of 6 x 5 current meters as can be seen from table (1), width of the channel being 3.5 meters.

<table>
<tr><td colspan="6">Intervals of the vertical rods (in meters) from the left side of the channel</td></tr>
<tr><td>0,25</td><td>0,85</td><td>1,45</td><td>2,05</td><td>2,65</td><td>3,25</td></tr>
<tr><td colspan="6">Intervals of the current meters in vertical direction from bottom to top</td></tr>
<tr><td>0,20</td><td>0,60</td><td>1,30</td><td>2,10</td><td colspan="2">2,85</td></tr>
</table>

Table (1): Measurement points in direction of flow

Due to the geometric conditions it was possible to work with the same arrangement of current meters in all four channels. All parties involved agreed to carry out the measurements in the direction of the flow behind the rack so that the losses behind the rack would not have to be considered separately. The six vertical rods were fixed by anchors on the nearly plain concrete bottom. The upper part of the rods was fixed by a strong crossbeam to completely eliminate vibrations during the measurement. The watertight connection cables of the current meters were lead to the water surface behind the measurement fence and connected to the computer in the machine hall of the power plant. According to IEC standard 41, article 10.2 the determination of discharge has to be realized with a minimum of 25 current meters. The compulsory minimum measurement time is 2 minutes total. For this measurement it was previously agreed to use 30 current meters and to measure for three minutes.

The velocity and the pulses of the current meters are monitored every 1/20 seconds, resulting in 3600 single measurement values per current meter and operating point. Together with the simultaneously monitored water level and the geometric cross-section profile the flow-through area can be determined. On the basis of the geometric conditions and the arrangement of current meters the velocity areas can be assigned accordingly.

2.1.1. Head

To determine the water level in the headwater a pressure measuring cell was installed on both vertical sides of the channel. To monitor the water level in the run-off water further probes were mounted in the relevant sections of the turbine directly at the end of the siphon pipes. Besides a tranquilized water level in the run-off water was supposed to be monitored which was measured in the run-out channel of an inactive turbine. All four probes were exactly calibrated by tachymetry. The measurement values of the water level probes were monitored parallel to the velocity by OTT MESSTECHNIK. Additionally, staff gauges were levelled and installed in the run-off water for plausibility control. Moreover a number of different reference points for the tachymetry was defined to avoid frequent moves of the measuring equipment as sources of error.

2.1.2. Power

The power supply company ENVIA installed monitoring devices in the control cabinets for the generated electric power for each generating set, providing a complete chain of data with a high time resolution over the two days.

Additionally the data was read out at the control cabinets and noted manually to record the power output of each measurement.

2.1.3. Water temperature and water quality

At each operating point the temperature of headwater and of the run-off water was measured. This value is also relevant for the density. Moreover samples were taken from the headwater. However, the analysis of these samples was postponed as almost no sedimentation of suspended load was recognized in the sample bottles and therefore the influence on the density is negligible.

2.1.4. Configuration of Measuring Equipment

In image (2) and image (3) the position of the current meter measurement fence (measurement matrix) and the pressure measuring cells is drafted.

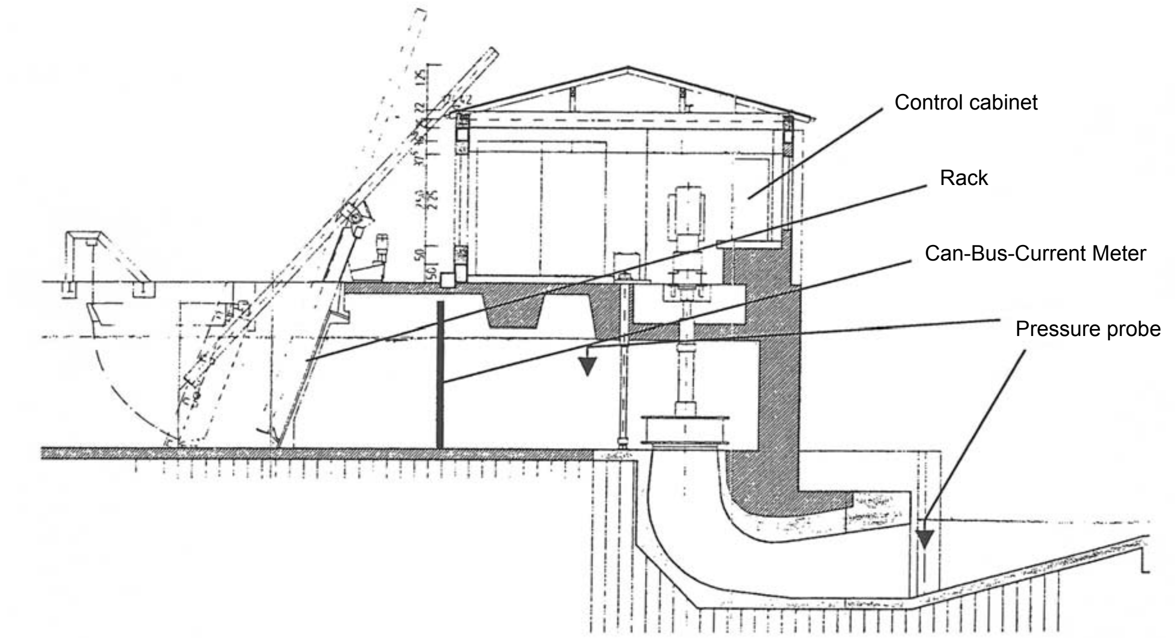

Image (2): configuration of the measuring equipment – section according to plot "ground plan – section – views"

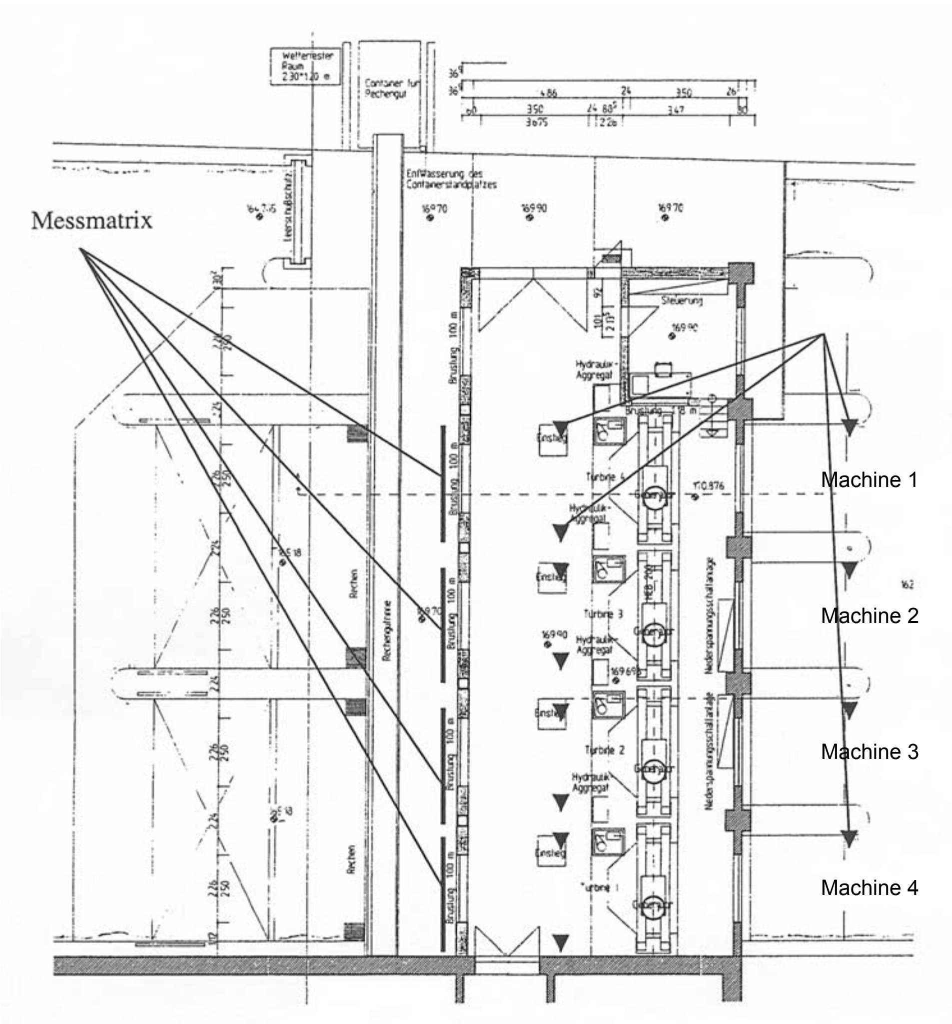

Image (3): configuration of the measuring equipment – site plan according to plot "ground plan – section – views"

3. Evaluation of Measured Data

As to the minutes of November 19th, 2000 all test were to be carried out with the second machine in the same inflow channel running with approximately the same power. Only for tests Li307 and Li308 only machine 3 was running while machine 4 was switched off. This test should give information about the influence of changes in the way of operation on the power output.

For evaluation purposes the tests were named according Table (2).

The part load was set at the control cabinet before the tests were started. In order to avoid heavy fluctuations in the power plant channel the additional gate was partly opened at small part loads and was gradually closed when part load was increased.

Machine	2^{nd} machine running	part load	test number
1	2	50 %	Li101
1	2	60 %	Li102
1	2	70 %	Li103
1	2	80 %	Li104
1	2	90 %	Li105
1	2	100 %	Li106
2	1	47 %	Li201
2	1	57 %	Li202
2	1	67 %	Li203
2	1	77 %	Li204
2	1	87 %	Li205
2	1	100 %	Li206
3	4	47 %	Li301
3	4	57 %	Li302
3	4	67 %	Li303
3	4	77 %	Li304
3	4	87 %	Li305
3	4	100 %	Li306
3 alone	-	67 %	Li307
3 alone	-	87 %	Li308
4	3	47 %	Li401
4	3	57 %	Li402
4	3	67 %	Li403
4	3	77 %	Li404
4	3	87 %	Li405
4	3	100 %	Li406

Table (2) : Tests

For the evaluation of the power output of a generating set, the head between the measurement level in front of the turbine and the discharge at the siphon pipe is significant. Therefore the measurement matrix of the head is positioned in the direction of flow behind the rack. The run-off water is measured directly behind the siphon pipe when it flows out into the channel. Therefore no further power loss is considered.

3.1. Discharge

The evaluation of the velocity and the determination of discharges was made by the program Hydro11 after the measurements were completed. The following calculations are based on the results of Hydro 11 as this program uses the most suitable algorithms.

Hydro 11 by Hydrometrics calculates discharges according to ISO standard from the cross-section of the profile and the measured local flow velocities. In addition to the calculated discharge values the diagram of isolines (lines with same velocities) in the measurement level is edited.

3.2. Density

The density was determined from the measured temperature according to the chart in IEC 41, page 371. The water samples were not analyzed as the content of sediment was obiously very low.

4. Error calculation

Error calculation was carried out according to ICE 41, article 6 and annex A and C. In general a confidence interval of 95% is prescribed for all calculations. The error calculation differs between random $\mathbf{f}_r$ (%) and systematic errors $\mathbf{f}_s$ (%). Finally both errors are integrated as one error, the root extracted from the sum of the squares. The range within which, with a probability of 95%, the expected value for the required variable – in this case the efficiency factor- is situated is calculated from $\eta \pm \mathbf{f}_\eta$

5. Determination of efficiency

5.1. Basics

The measured values Q_i, h_i, P_i and p_i used in the statistical evaluation are integrated in the known water power formula

$$P_i = p_i \times Q_i \times g \times h \times \eta_{ges,masch,act}$$

Meaning:

i	measured operating point
P_i	efficiency at the generator clamp (W)
p_i	densitiy (kg/m^3)
Q_i	discharge (m^3/s)
g	acceleration of gravity
h_i	relevant head for the efficiency of the generator sets (m)
$\eta_{ges,masch,\ act}$	actual calculated total efficiency (-)

The total efficiency $\eta_{ges,masch,\ act}$ of the generating set refers to the water quantity and the head difference between inflow at the turbine (here: measurement fence level in the headwater) and the end of the siphon pipe as power input, and to the electrical power output at the generator clamp.

As all values of above equation are measured and as losses are considered as well, if necessary, after conversion of the equation 5.1. the total efficiency can be calculated by the formula

$$\eta_{ges,masch,\ ist} = \frac{Pi}{p_i \times Q_i \times g \times h}$$

The total efficiency $\eta_{ges,masch,\ act}$ as it has been calculated from the measurements has to be compared to the total efficiency $\eta_{ges,masch,\ nom}$ (nominal value) which is stated and guaranteed by the manufacturer of each generating set at different admissions of the turbines.

The guaranteed partial efficiencies have been taken from the purchase contract concluded between the parties on March 3rd, 1995. From those the total efficiencies were calculated for cos Φ=0.8 for generating sets equipped with synchronous alternators.

An evaluation of the partial efficiencies (gear unit, generator and turbine) is not possible in the framework of the actual investigation as the breakdown was monitored by single measurements.

5.2. Results

From the nominal efficiency $\eta_{ges,masch,\ nom}$ indicated by the turbine manufacturer for various admissions and from the actual efficiencies $\eta_{ges,masch,\ act}$ (see table (3)) functions were made up by spline interpolation.

Part load	η machine 1	η machine 2	η machine 3	η machine 4
50/47	68,17%	66,52%	65,44%	62,01%
60/57	78,39%	73,14%	74,21%	70,65%
70/67	82,06%	78,32%	77,68%	77,12%
80/77	82,61%	79,30%	83,72%	78,30%
90/87	79,34%	78,42%	81,85%	78,48%
100	78,94%	77,43%	81,39%	76,31%
67 alone			78,67%	
87 alone			79,63%	

Table (3): Total degree of efficiency calculated on the basis of measured values

Chart 1 to 4. show for each generating set the calculated average actual efficiency $\eta_{ges,masch,\ act}$ with error tolerances taking into consideration a 95% confidence interval and the guaranteed total degrees of efficiency $\eta_{ges,masch,\ nom}$. Basically, three situations have to be considered:

- If the guaranteed nominal efficiency lies within the curve of the actual efficiency incl. tolerances, the guaranteed performance is fulfilled.
- If the guaranteed nominal efficiency lies over the curve of the tolerance for the 95% confidence interval of the measured actual value the guaranteed performance is not fulfilled.
- If the guaranteed nominal efficiency lies below the tolerance curve, the guaranteed performance is fulfilled.

The images show the different courses of the measured actual efficiency and the guaranteed nominal efficiency.

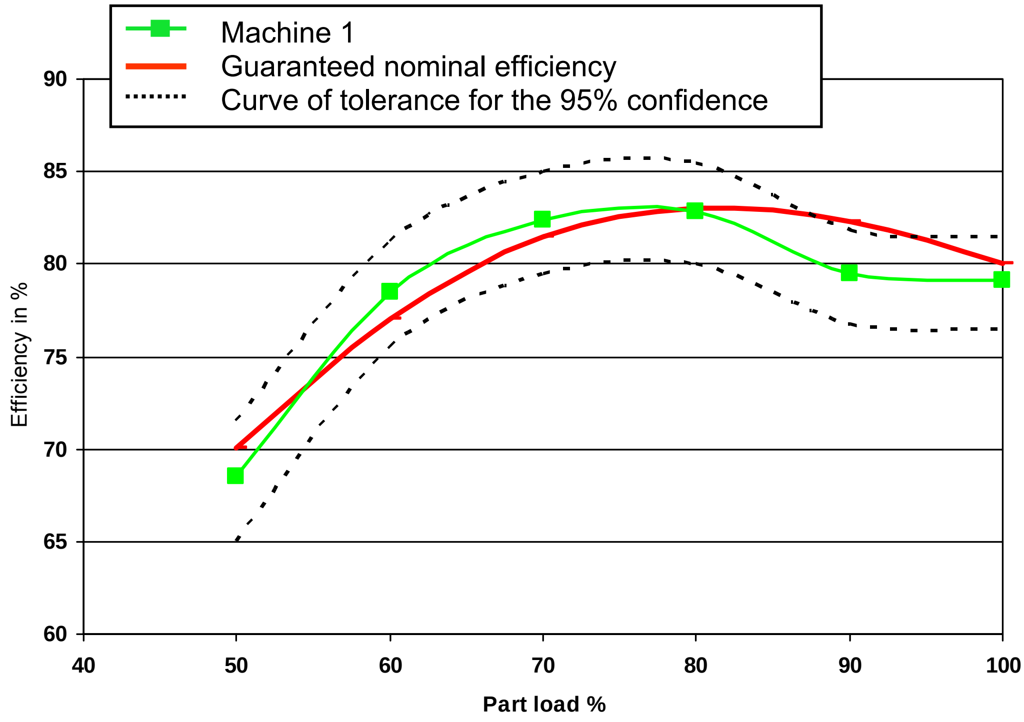

Chart (1): Comparison of the results for machine 1

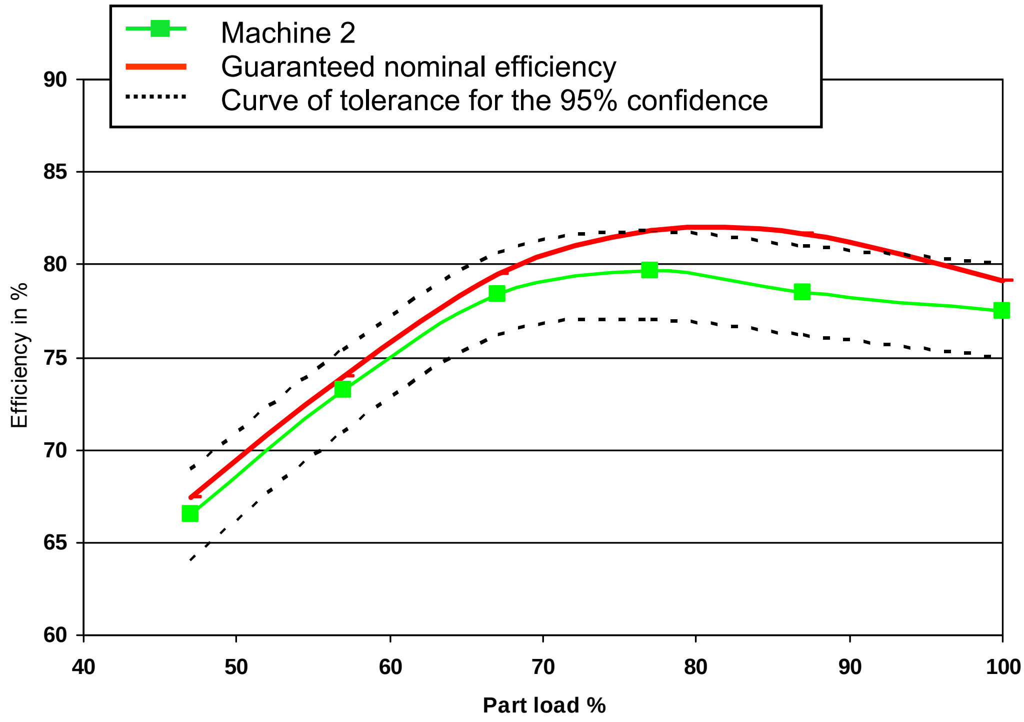

Chart (2): Comparison of the results for machine 2

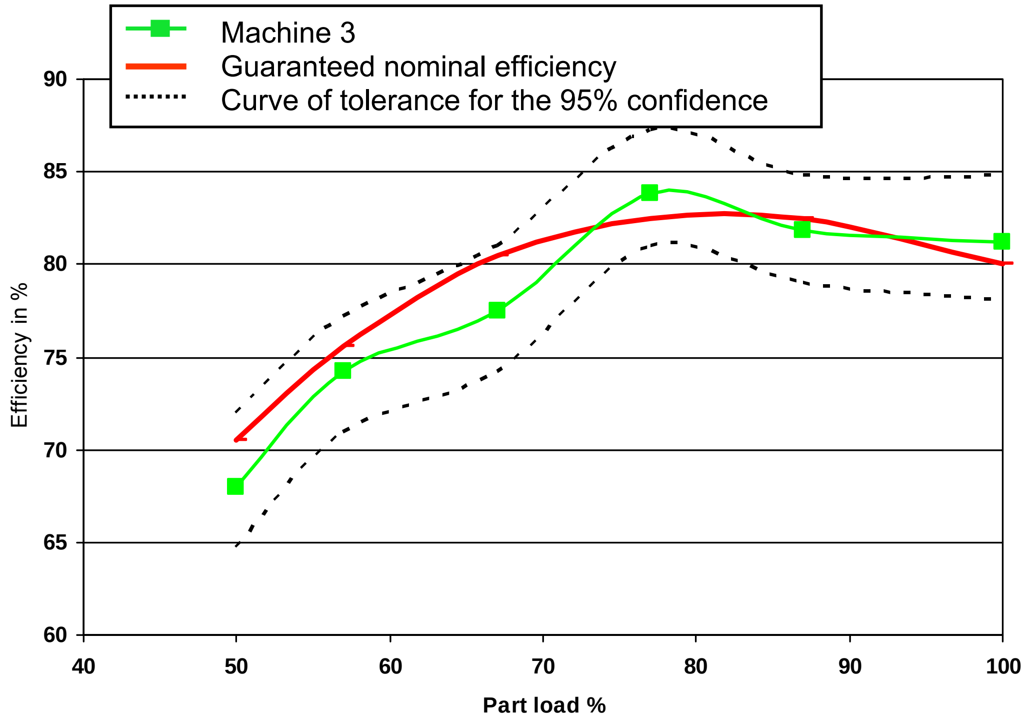

Chart (3): Comparison of the results for machine 3

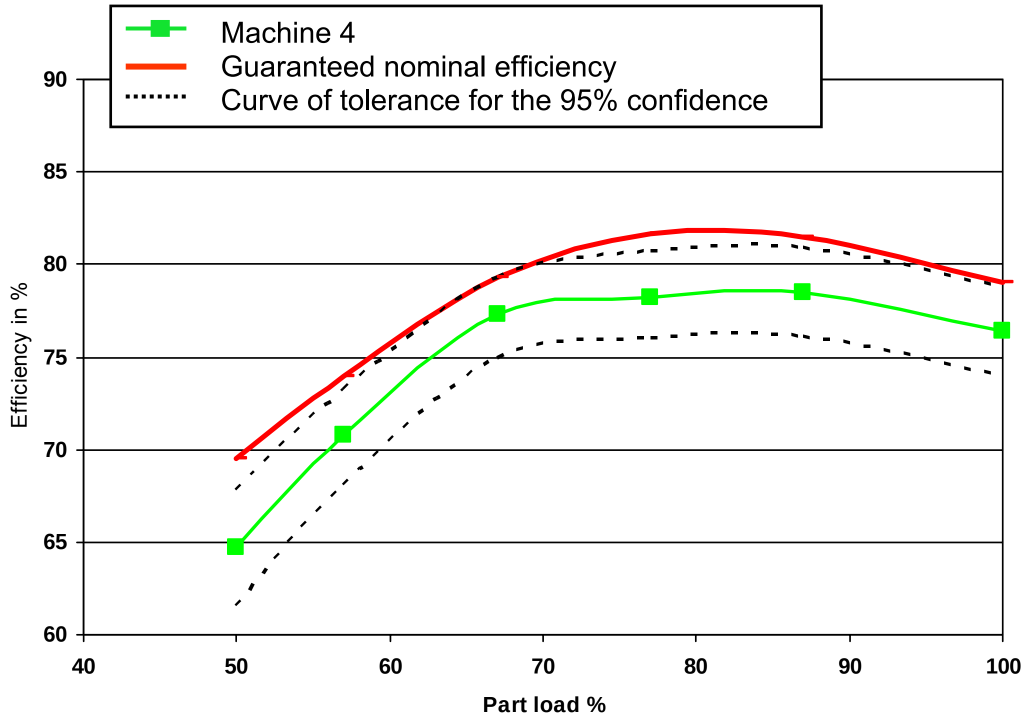

Chart (4): Comparison of the results for machine 4