A new generation of hydrounit monitors*

By Branko Bajic
Korto Cavitation Services, Luxembourg, Luxembourg
www.korto.com info@korto.com

ABSTRACT

Monitoring of a hydro unit can be performed by a simple system and still be very efficient if a multidimensional approach is applied to signal sensing and to signal and data processing. The advantages of this concept are low costs and easier maintenance, which make it suitable for all units and plants and not only for the large ones. The output of such a system and some typical applications are illustrated.

Introduction

If the system used to monitor hydro unit operation is separated from the system used to control it, the monitoring system can be rather simple. By organizing the monitoring in a multidimensional way, the functionality of such a simple system can surpass a system based on complex hardware and a costly collection of specialized software subsystems, which is a common configuration offered on the world market. The term ***multidimensional*** is used to describe a monitoring algorithm based on the full usage of observable data on all the dimensions of monitored processes. This implies suitable sampling of all the quantities in space, time, rotor instantaneous position, frequency, and the domain of state variables; true multidimensional processing of such data; using direct and hidden inter-relationships among the data; and optimizing the monitoring algorithm based on secondary data yielded by such a procedure.

The multidimensional concept was initially introduced for the diagnostics and monitoring of cavitation [1]. First, turbines with a high number of runner blades were considered. The concept was later broadened to the case of a low number of runner blades as well [2]. This approach was based on a detailed study of sensors and signal and data processing problems [3]. Several examples of successful application have been presented [1, 2, 4, and 5].

In this paper, the concept of general multidimensional monitors is illustrated. Such simple and inexpensive but effective systems might well be the next generation of hydropower unit monitors, offering a solution well-suited for plants and units of all sizes.

Implementation

The best strategy of devising a monitoring system for a unit under consideration is:

- perform first a diagnostic test on it;
- use the operators' insights and the diagnostic test results to define the list of quantities to be monitored; optimize the selection, number, and location of sensors;
- adapt the multidimensional algorithm to the unit.

By following this strategy, rather than installing a pre-defined "one size fits all" system, the monitoring system can be cost-effectively tailored to the unit-specific or plant-specific issues. The last step of matching the multidimensional algorithm to the particularities and peculiarities

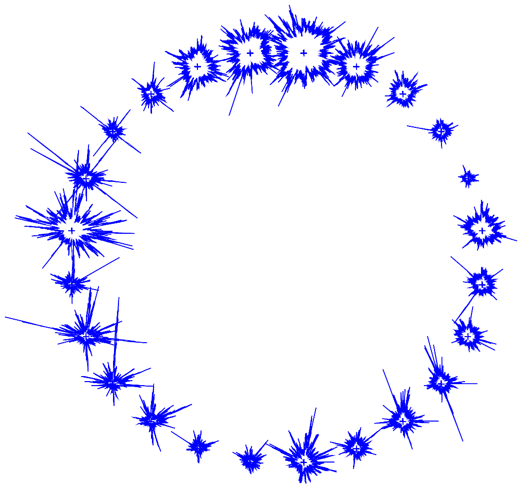
---

* Presented at the HydroVision 2004 Conference,
August 14-20, 2004, Montréal, Québec, Canada

of the unit is crucial. This ensures high sensitivity for detecting deterioration effects and improves monitoring reliability.

Whatever the result of such an optimization, the monitoring system can be quite simple. It consists of sensors, a small industrial computer with an analog-to-digital conversion card, and multidimensional software. No additional analog units are needed with suitable selection of the A-D card. This reduction in hardware reduces costs, simplifies maintenance, and permits easy reconfiguration of the system.

Sensing



Problems with sensing dynamic signals are illustrated here using an example of cavitation diagnostics. The figure shows the results from a cavitation test performed on a bulb unit, and similar results are exhibited by Francis and Kaplan units. The sensors in 24 positions around the turbine runner yielded 24 curves as shown. These curves describe the dependence of cavitation noise power (radial co-ordinate) on the instantaneous angular position of the runner (angular co-ordinate). The peaky structure of the curves reflects the changes in cavitation conditions that the runner blades experience while passing through the wake fields of guide vanes. Each peak is related to a single blade-vane pair, and analysis of such curves yields data on cavitation qualities of individual runner blades and data on the influence individual guide vanes have on cavitation.

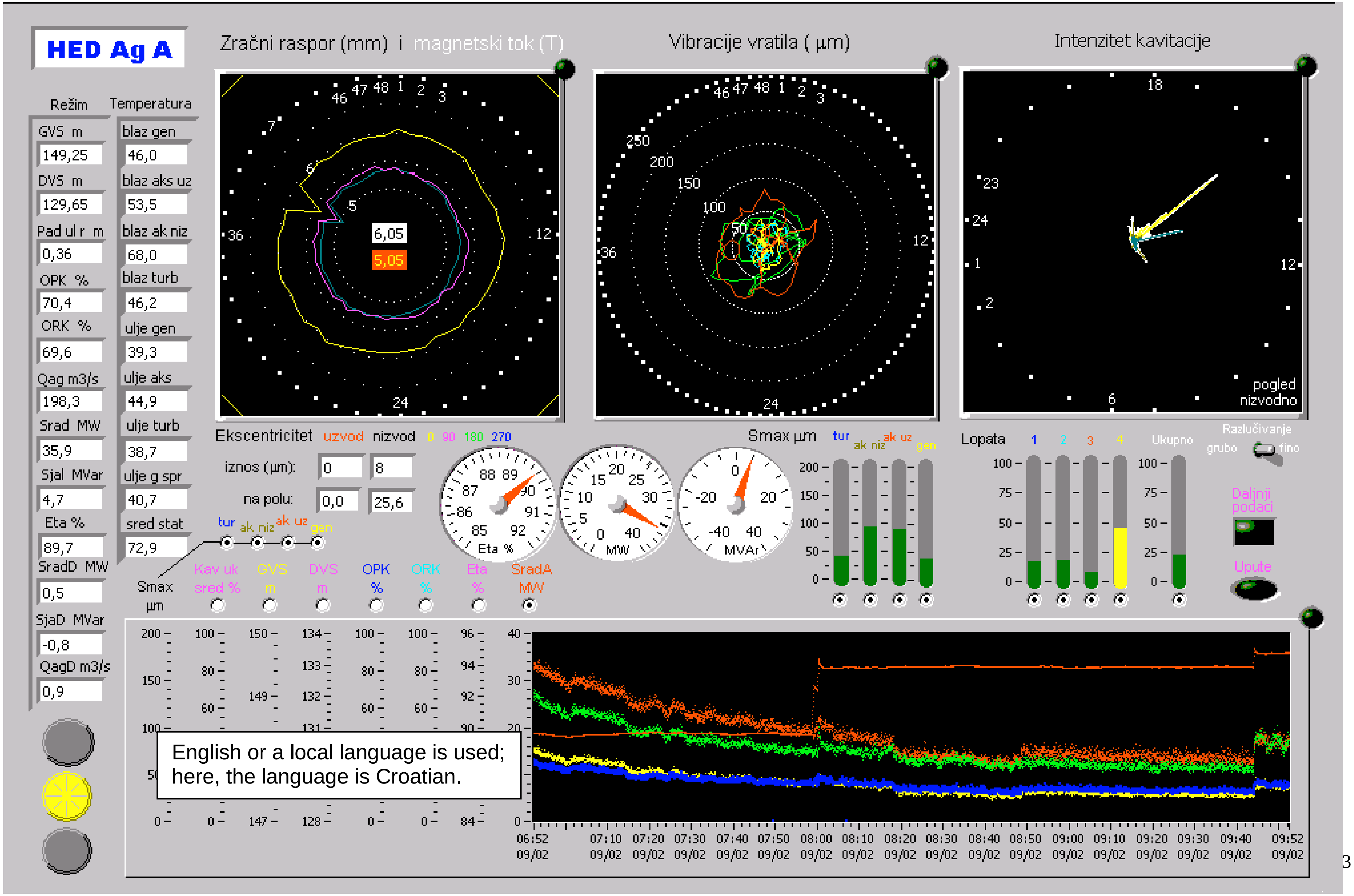
The curves in the figure differ significantly, both in form and in mean value. Thus, by taking into account only one or few sensors, incorrect estimates of the cavitation intensity related to pairs might be obtained, and the same holds for the mean intensity estimates. Therefore, in order to get a true characterization of cavitation in a turbine, either in the form of detailed data or in the form of data on the total cavitation in the turbine, one must use a sufficiently high number of sensors suitably distributed over the turbine. Cavitation monitors that spare on sensors may yield non-representative results.

Processing

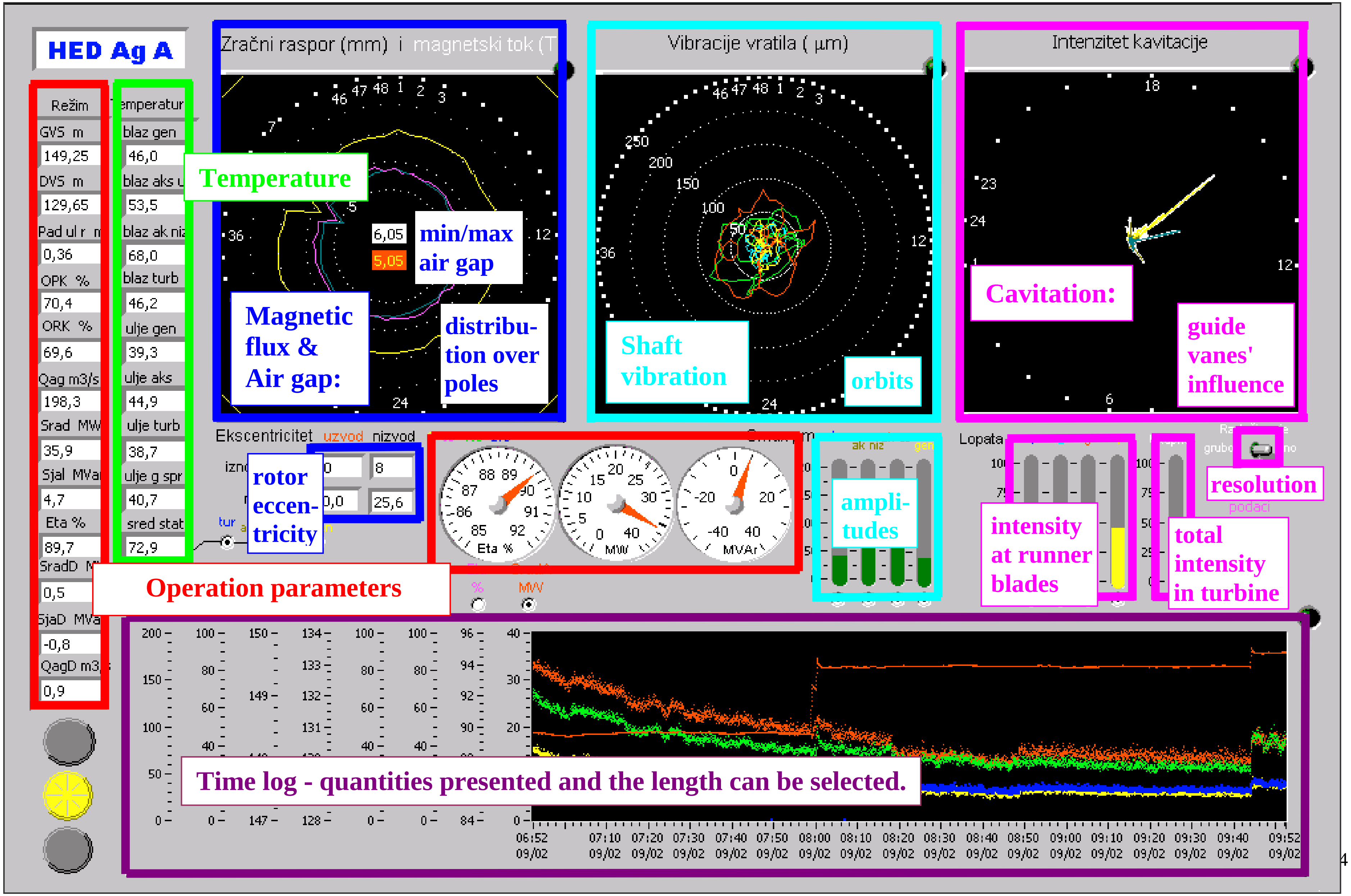
The situation with respect to spatial sensing, illustrated here by cavitation, is encountered while monitoring other dynamic quantities as well. The same holds true for the algorithms used to process signals and acquired data. A particular ***analysis-synthesis*** procedure is needed in order to make the results interpretable and reliable. Using the cavitation example above, this procedure can be presented as follows: (1) decompose the peaky structures of strongly mixed contributions from different blade-vane pairs; (2) distinguish between different cavitation mechanisms; and then (3) synthesize quantities such as the intensity of a particular mechanism on a particular blade behind a particular vane.

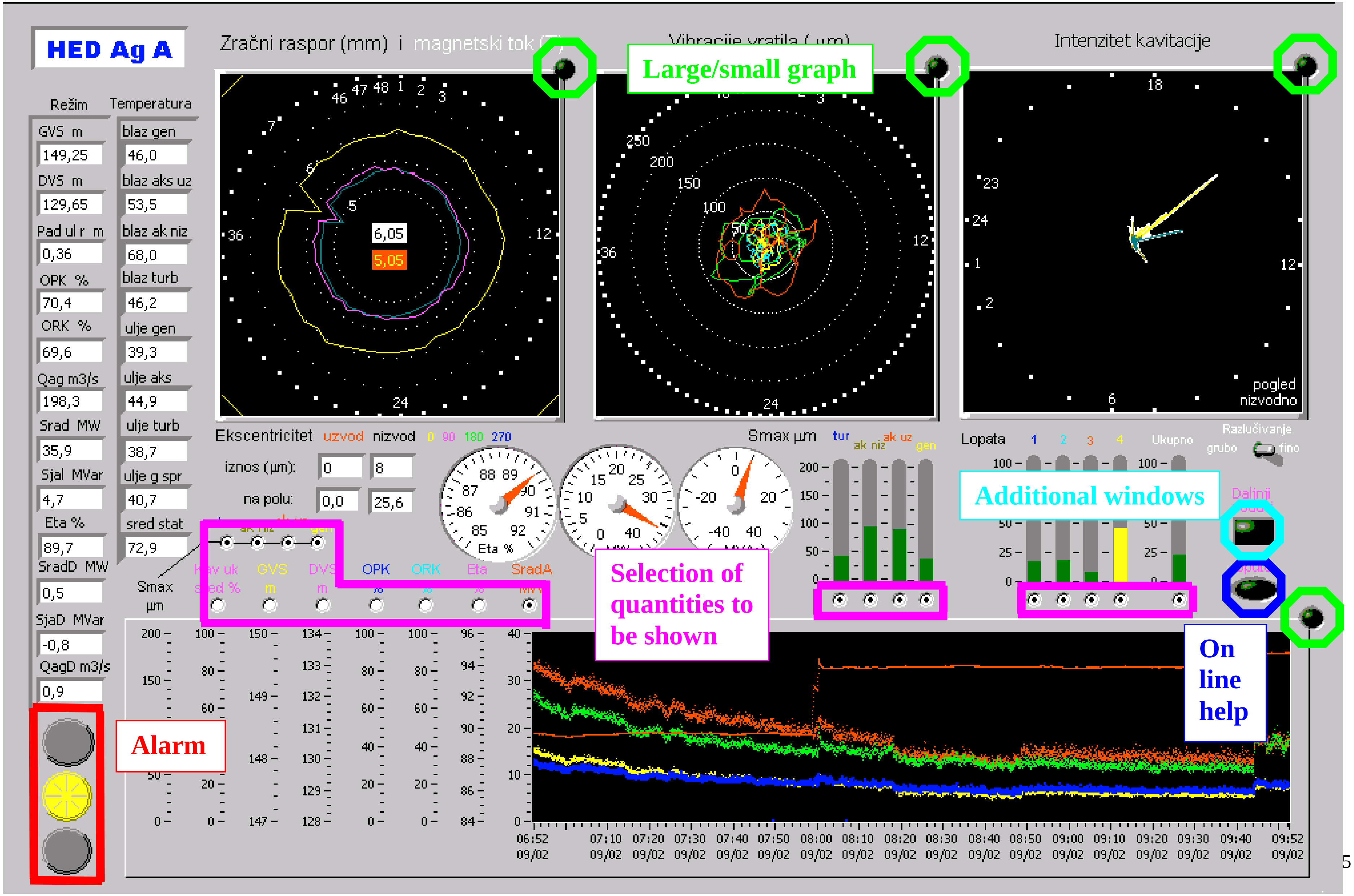
Data presentation

In several figures that follow the typical output of a monitor is illustrated. The design bringing all important data in the basic window is adopted, and for details, one clicks further.

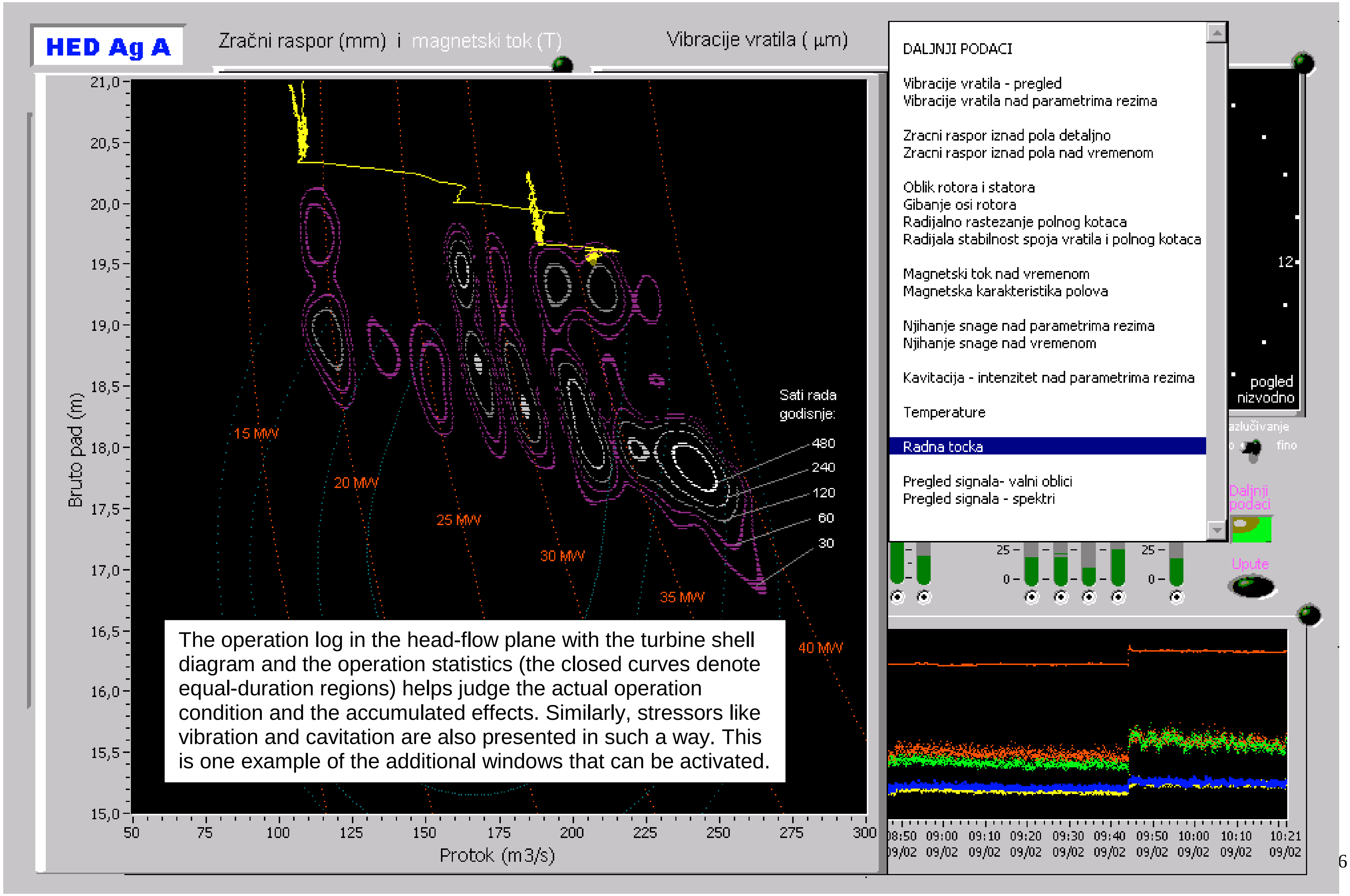

HED Ag A
Zračni raspor (mm) i magnetski tok (T)
Vibracije vratila (µm)
Intenzitet kavitacije
Režim
Temperatura
GVS m
149,25
DVS m
129,65
Pad ul r m
0,36
OPK %
70,4
ORK %
69,6
Qag m3/s
198,3
Srad MW
35,9
Sjal MVar
4,7
Eta %
89,7
SradD MW
0,5
SjaD MVar
-0,8
QagD m3/s
0,9
blaz gen
46,0
blaz aks uz
53,5
blaz ak niz
68,0
blaz turb
46,2
ulje gen
39,3
ulje aks
44,9
ulje turb
38,7
ulje g spr
40,7
sred stat
72,9
6,05
5,05
pogled nizvodno
Ekscentricitet uzvod nizvod 0 90 180 270
iznos (µm): 0 8
na polu: 0,0 25,6
Smax µm
tur ak niz ak uz gen
Eta %
MW
MVAr
Lopata 1 2 3 4 Ukupno
Razlučivanje
grubo fino
Daljnji podaci
Upute
Kav uk sred %
GVS m
DVS m
OPK %
ORK %
Eta %
SradA MW
English or a local language is used; here, the language is Croatian.

3

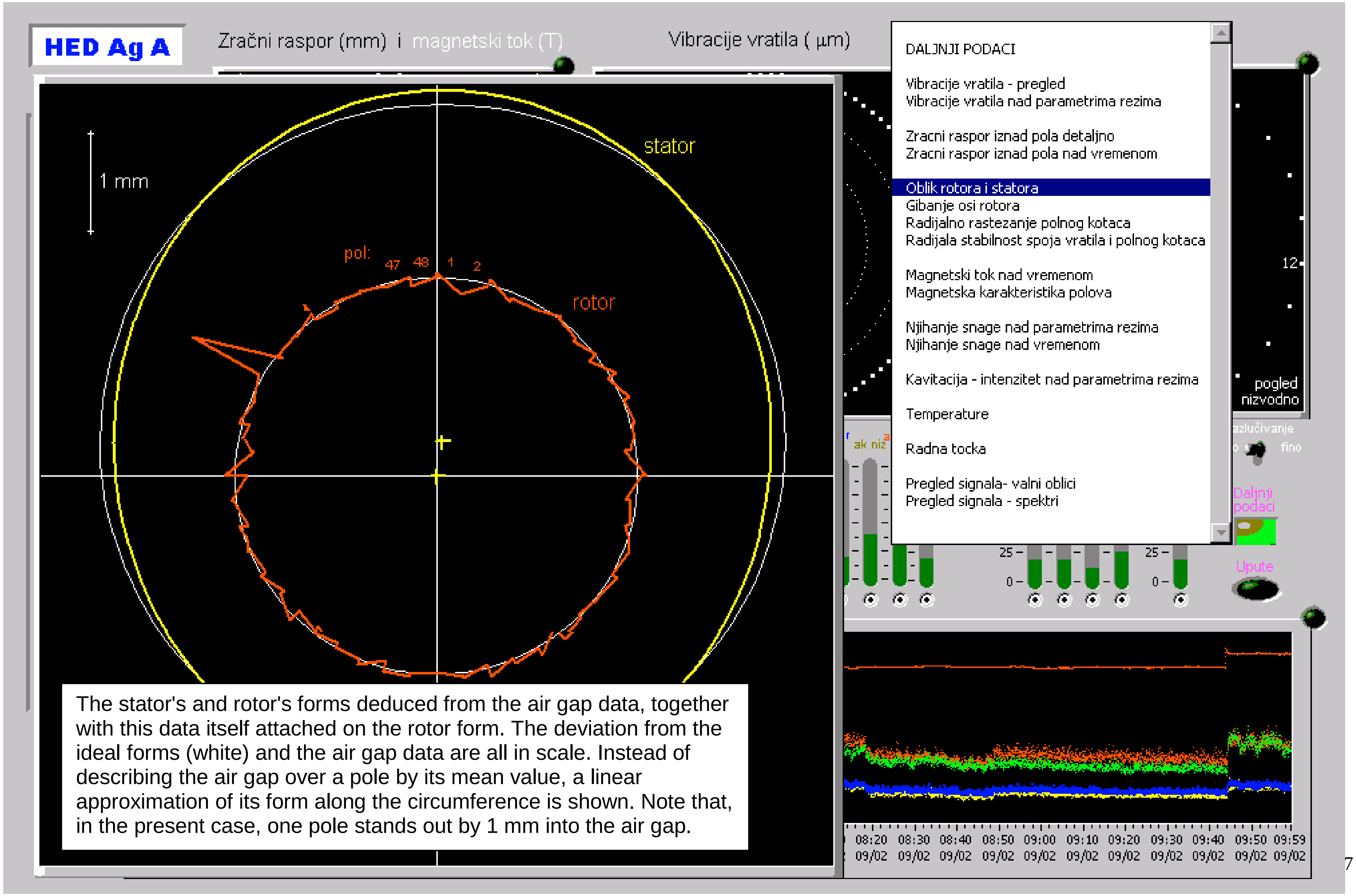

HED Ag A
Režim
GVS m
149,25
DVS m
129,65
0,36
OPK %
70,4
ORK %
69,6
198,3
35,9
4,7
Eta %
89,7
0,5
-0,8
0,9
blaz gen
46,0
53,5
68,0
blaz turb
46,2
ulje gen
39,3
ulje aks
44,9
ulje turb
38,7
40,7
sred stat
72,9
Temperature
Zračni raspor (mm) i magnetski tok (T
6,05
5,05
min/max air gap
Magnetic flux & Air gap:
distribu-tion over poles
Vibracije vratila (µm)
Shaft vibration
orbits
Intenzitet kavitacije
Cavitation:
guide vanes' influence
Ekscentricitet uzvod nizvod
rotor eccen-tricity
25,6
Eta %
MW
MVAr
ampli-tudes
Lopata
intensity at runner blades
total intensity in turbine
resolution
Operation parameters
Time log - quantities presented and the length can be selected.



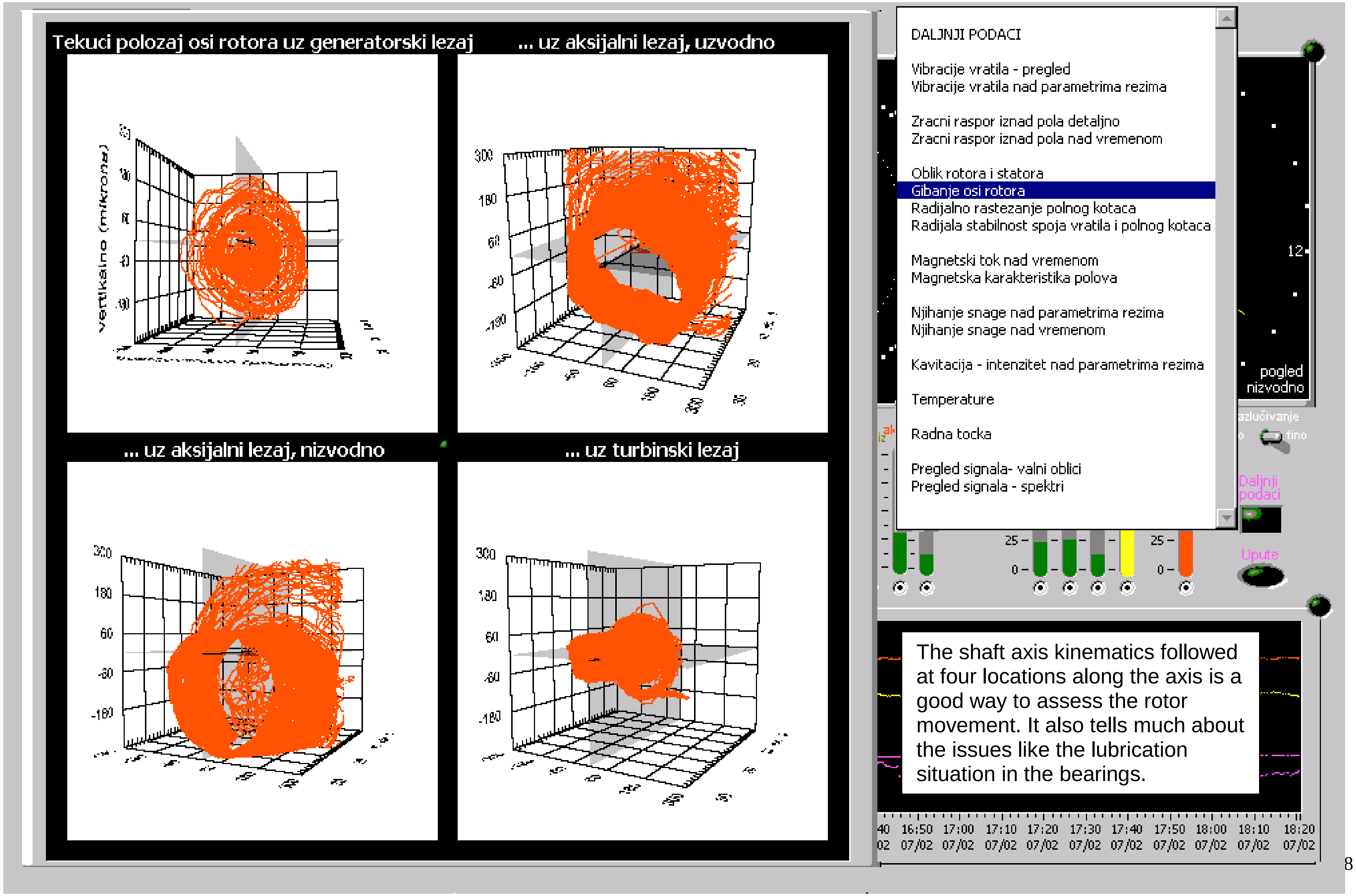
HED Ag A
Zračni raspor (mm) i magnetski tok
Vibracije vratila (µm)
Intenzitet kavitacije
Large/small graph
Režim
Temperatura
GVS m
149,25
DVS m
129,65
Pad ul r m
0,36
OPK %
70,4
ORK %
69,6
Qag m3/s
198,3
Srad MW
35,9
Sjal MVar
4,7
Eta %
89,7
SradD MW
0,5
SjaD MVar
-0,8
QagD m3/s
0,9
blaz gen
46,0
blaz aks uz
53,5
blaz ak niz
68,0
blaz turb
46,2
ulje gen
39,3
ulje aks
44,9
ulje turb
38,7
ulje g spr
40,7
sred stat
72,9
6,05
5,05
pogled nizvodno
Ekscentricitet
uzvod
nizvod
0
90
180
270
iznos (µm):
0
8
na polu:
0,0
25,6
Eta %
Smax µm
tur
ak niz
ak uz
gen
Lopata
1
2
3
4
Ukupno
Razlučivanje
grubo
fino
Additional windows
Smax µm
OPK %
ORK %
Eta %
SradA MW
Selection of quantities to be shown
Alarm
On line help
06:52 09/02
07:10 09/02
07:20 09/02
07:30 09/02
07:40 09/02
07:50 09/02
08:00 09/02
08:10 09/02
08:20 09/02
08:30 09/02
08:40 09/02
08:50 09/02
09:00 09/02
09:10 09/02
09:20 09/02
09:30 09/02
09:40 09/02
09:52 09/02



The operation log in the head-flow plane with the turbine shell diagram and the operation statistics (the closed curves denote equal-duration regions) helps judge the actual operation condition and the accumulated effects. Similarly, stressors like vibration and cavitation are also presented in such a way. This is one example of the additional windows that can be activated.



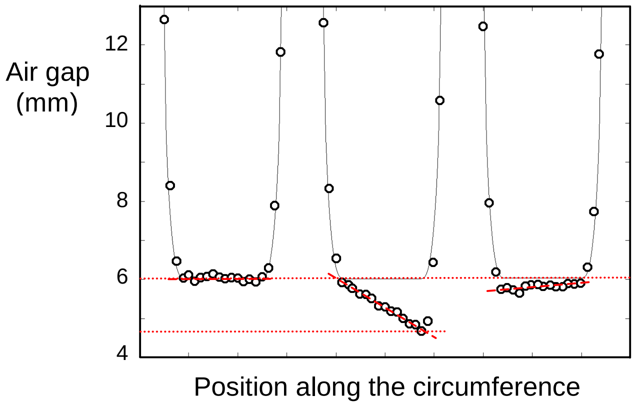
The stator's and rotor's forms deduced from the air gap data, together with this data itself attached on the rotor form. The deviation from the ideal forms (white) and the air gap data are all in scale. Instead of describing the air gap over a pole by its mean value, a linear approximation of its form along the circumference is shown. Note that, in the present case, one pole stands out by 1 mm into the air gap.

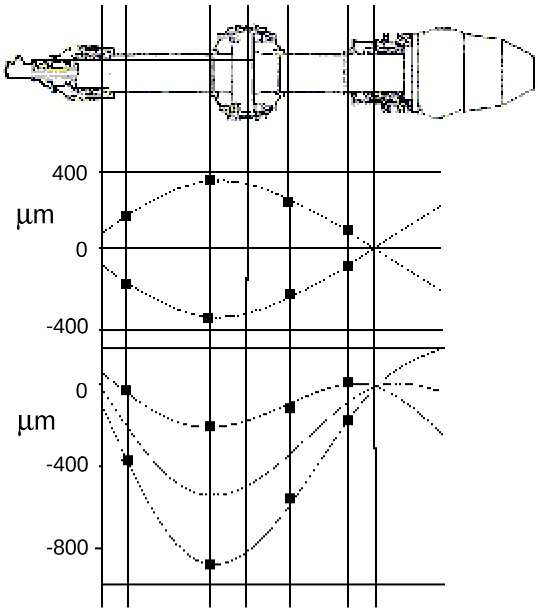

Tekuci polozaj osi rotora uz generatorski lezaj
... uz aksijalni lezaj, uzvodno
... uz aksijalni lezaj, nizvodno
... uz turbinski lezaj
vertikalno (mikrona)
DALJNJI PODACI
Vibracije vratila - pregled
Vibracije vratila nad parametrima rezima
Zracni raspor iznad pola detaljno
Zracni raspor iznad pola nad vremenom
Oblik rotora i statora
Gibanje osi rotora
Radijalno rastezanje polnog kotaca
Radijala stabilnost spoja vratila i polnog kotaca
Magnetski tok nad vremenom
Magnetska karakteristika polova
Njihanje snage nad parametrima rezima
Njihanje snage nad vremenom
Kavitacija - intenzitet nad parametrima rezima
Temperature
Radna tocka
Pregled signala- valni oblici
Pregled signala - spektri
pogled nizvodno
Daljnji podaci
Upute
The shaft axis kinematics followed at four locations along the axis is a good way to assess the rotor movement. It also tells much about the issues like the lubrication situation in the bearings.

Application examples

Pole-shape identification

A detailed survey of the air gap variation along the pole's circumferential length, shown in figure, yields details on the pole finish and its mounting. Here, three neighboring poles are compared to the ideal shape. One pole stands out strongly and is inclined.



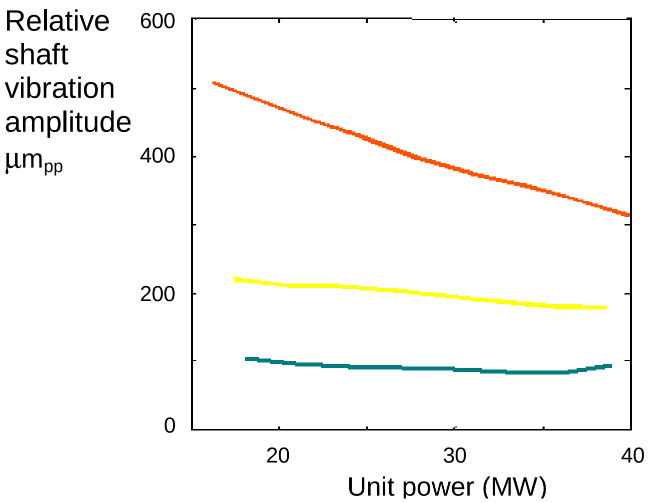


Vibration modeling

An elastic-beam model drawn through the *relative shaft vibration amplitude* data as sensed along the shaft describes well the true form of the vibration distribution in the horizontal plane (upper graph) and the vertical plane (lower graph). Adding to this few plausible assumptions, one gets a tool that predicts machinery loading and describes circumstances in the bearings, which are otherwise hard to assess. Further, the model reduces data needed to describe vibration and makes that description robust.

Vibration reduction

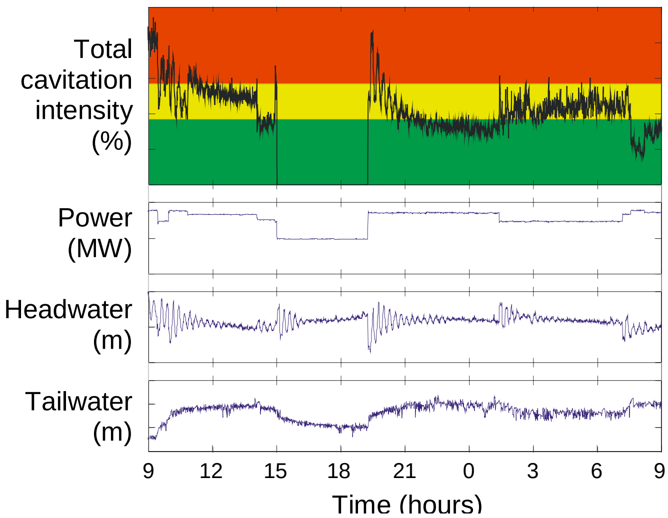
A unit suffered from severe shaft vibration. Magnetic flux data revealed the cause, and air gap data yielded a detailed description of shaft kinematics. This facilitated an efficient two-step counter-measure which suppressed the vibration amplitude by a factor 3-5 from Initial to Centered and then to Counter-Centered [6].

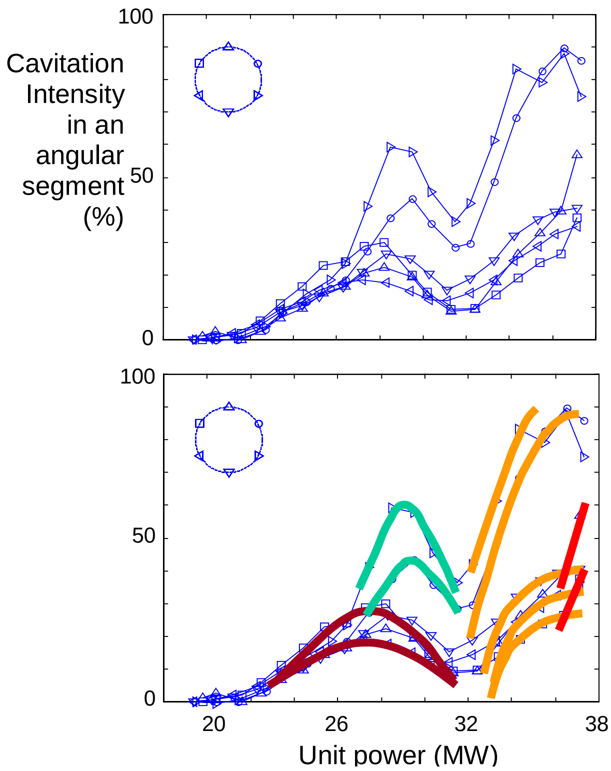


Cavitation monitoring

The multidimensional algorithm, based on 4-8 sensors per unit, yields:

- a reliable and true estimate of the total cavitation intensity (right),
- intensity of cavitation at a runner blade,
- data on the guide vanes' influence.
  All this comes
- with or without spatial resolution, and
- with or without resolution over cavitation mechanisms (different types of cavitation or cavitation in different locations).





Spatial resolution

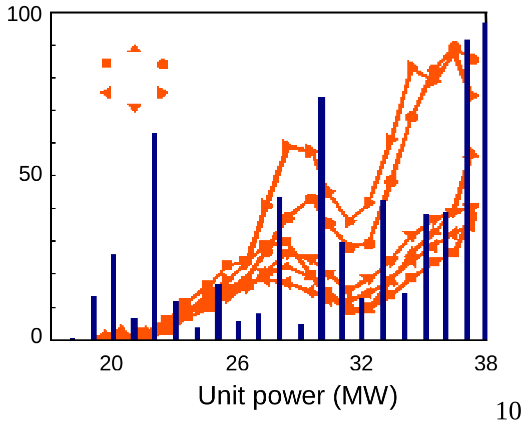
In a large-diameter bulb unit monitored, cavitation was strongly varying in the vertical plane. This was quantified by the analysis resolving angular segments of the flow. A shift of the intensity maximum in the rotation direction (clockwise) is observed.

Cavitation mechanisms

Almost regularly, one finds several cavitation processes in a turbine; there are 4 in the example shown. It is necessary to distinguish between them, since - depending on the aim of monitoring - not all are important (e.g., not all are erosive).

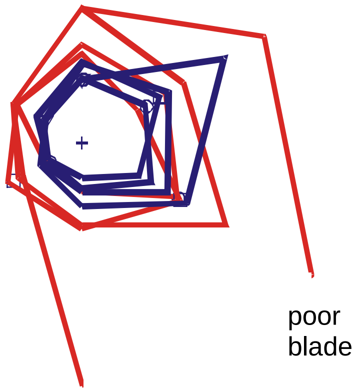
Operation optimization

Combining the results like those illustrated above (red) with the statistics of head, tailwater, and power values (blue), one can optimize unit operation for a minimum accumulated cavitation erosion (which is also monitored).

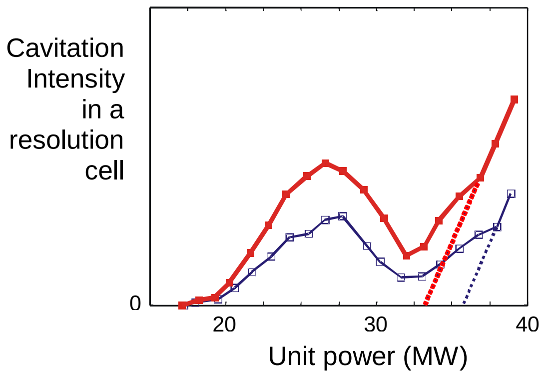


Turbine instability

Cavitation monitoring resolving angular segments in a turbine and yielding data on each runner blade independently was used, in a case illustrated here, in two operational situations:
blue - normal;
red - with trash caught on guide vanes.
Radial co-ordinate - cavitation intensity;
angular co-ordinate - position of a segment.
The four curves in each color, corresponding to four blades, show that, when the trash is acting, one poor blade cavitates explosively within a portion of a revolution. This was recognized as the cause of strong once-per-revolution power fluctuations the unit suffers from.



Malfunction detection



In order to test the sensitivity of a monitor's cavitation channel to changes in turbine's behavior or deterioration effects, one guide vane was slightly shifted from its normal position. In the related spatial resolution cell of monitor's output, strong change was found -
blue - normal vane position,
red - shifted:
cavitation was intensified and its threshold shifted towards lower loading. At the same time, there was no recognizable change in the output showing the total intensity of cavitation in the turbine. This illustrates another quality of the multidimensional monitor. By involving resolution in important variables, it ensures extremely high sensitivity in the detection of the deterioration effects.

Conclusion

This paper describes a simple multidimensional monitor which provides a cost-effective alternative to large and expensive systems for monitoring hydropower units. Implementation of the monitor is preceded by a diagnostic test, and the monitor is based on a multi-dimensional algorithm.

The multidimensional cavitation monitor, implemented independently or as a part of a general monitoring system, distinguishes between turbine parts and between cavitation mechanisms; it yields detailed data on cavitation, useful for diagnostics and operation optimization; and it detects changes and deterioration effects with a high sensitivity.

References

1. B. Bajic, "Multi-dimensional diagnostics of turbine cavitation," Journal of Fluids Engineering, Vol. 124, No. 4, 2002, pp. 943-950
   (presented initially at the 20th IAHR Symposium Hydraulic Machinery and Systems, Charlotte, North Carolina, U.S.A., August 2000).
2. B. Bajic, "Cavitation diagnostics and monitoring," International Water Power & Dam Construction, Vol. 56, No. 2, 2003, pp. 32-35.
3. B. Bajic, "Methods for vibro-acoustic diagnostics of turbine cavitation," Journal of Hydraulic Research, Vol. 41, No. 1, 2003, pp. 87-96.
4. B. Bajic, "Vibro-acoustical diagnostics of turbine cavitation - Examples of application," HydroVision 2000 Conference, Charlotte, North Carolina, U.S.A., August 2000.
5. B. Bajic, "Turbine instability explained by multidimensional cavitation diagnostics," Hydro 2003 Conference, Dubrovnik, Croatia, November 2003.
6. Dj. Dvekar, B. Bajic, I. Bacinger, D. Magic, J. Sabolek, and M. Demirovic, "Suppression of shaft vibration on a bulb unit, based on detailed rotor diagnostics," Hydro 2001 Conference, Riva del Garda, Italy, September 2001.

Author

Dr. B. Bajic, managing director of Korto Cavitation Services, has extensive experience with vibro-acoustic phenomena of cavitation, dynamic process analysis, signal and data processing, and other attributes of monitoring system design and use. He has developed and implemented several innovative methods for vibro-acoustic diagnostics and monitoring of turbine cavitation.