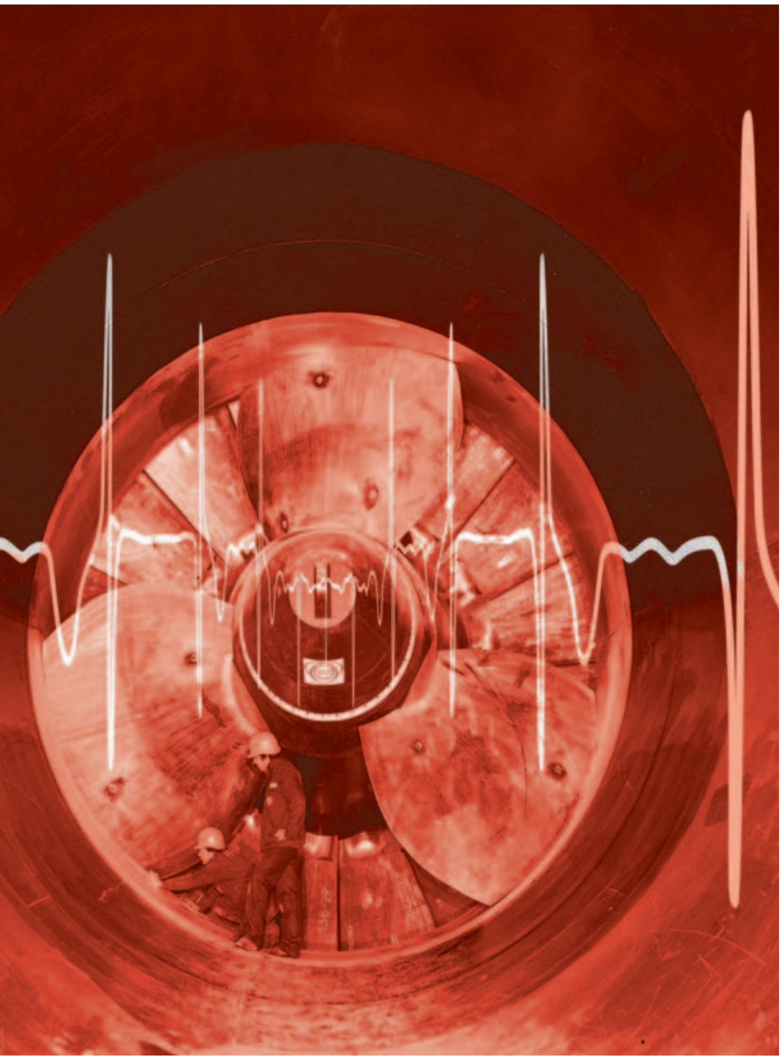


Cavitation diagnostics and monitoring

Branko Bajic reports on new developments in a multidimensional technique for turbine cavitation diagnostics and monitoring

ARE there different types of cavitation in a turbine? How strong is cavitation in different locations within a turbine? What is the cavitation quality of individual turbine parts? What is the role of cavitation in power fluctuations? How does trash influence the unit behaviour? Korto Cavitation Services believes its multidimensional technique for turbine cavitation diagnostics and monitoring yields useful details on cavitation processes and answers these questions. The technique is sensitive enough to detect deterioration during the early phases of development and provides a reliable basis for operation optimisation. It yields rich data on the causes of changes in turbine cavitation behaviour that facilitate reliable diagnostics and optimisation of the repair schedule.

The technique, described in the May 2001 issue of IWP&DC (pp33-36), has so far been used for turbines with a high number of runner blades. The variant of the technique suitable for turbines with a low number of runner blades is illustrated here by the example of a 40MW bulb turbine (denoted A) at the Dubrava hydroelectric station, sited on the Drava river in Croatia.

The example shows how detailed data on cavitation not obtainable by simpler techniques can be derived. It allows for identification of different cavitation mechanisms that occur in a turbine, assessment of cavitation quality of turbine parts, and the explanation of a peculiar dynamic behaviour of the unit.

Cavitation monitoring

The cavitation behaviour of Dubrava A at a high power setting is shown in figure 2. The radial co-ordinate denotes cavitation intensity and the angle co-ordinate shows the instantaneous angular position of the runner. The peaks indicate the variability of cavitation within a revolution, stemming from the circumferential variations in the velocity field of the inflow to the runner. These variations are caused by the flow disturbances induced by the guide and stay vanes.

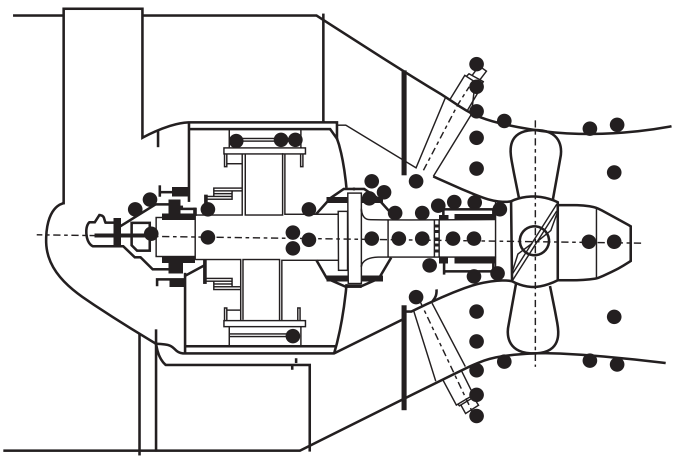
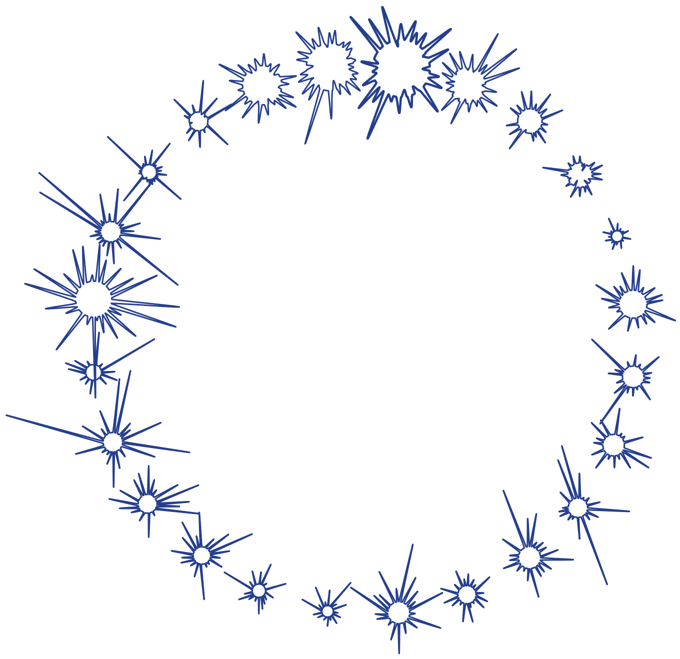


Figure 1 – The multidimensional diagnostic tests are based on a high number of various sensors mounted at carefully chosen locations all over the unit. For permanent monitoring, the number of sensors is reduced but is, especially for cavitation, still higher than commonly practised.



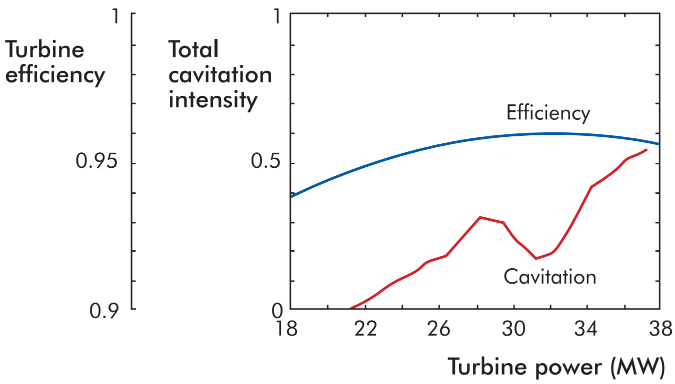
Above: Figure 2 – Polar presentation of the cavitation intensity dependence on the instantaneous angular position of the runner, as sensed in 24 locations around the runner.

Below: Figure 3 – The simplest cavitation monitor checks the basic turbine cavitation characteristics: the entire turbine is described by one numeric quantity.

The inflow variations and differences in guide vanes' quality with respect to cavitation also cause differences in the mean cavitation intensity in various locations around the runner. The implications for the cavitation monitor are obvious: if too few sensors are used for spatial sampling of cavitation then cavitation intensity might be strongly underestimated or overestimated. What is more, the data within the structure of the curves (which, when deciphered, yield data on the role guide vanes play in the cavitation process) would not be representative and thus would yield false diagnostic conclusions. Even if details on guide vanes are not required, the recorded data structure would be arbitrary and not all types and locations of cavitation would be properly taken into account.

The conclusion is that even the simplest cavitation monitor, expected to assess cavitation in a given operating condition by one numeric value only, should make use of a large number of spatially separated sensors to sample the cavitation. The final result, though simple, would then be derived from all the sensors combined. Such simple cavitation estimates may be used to optimise the operation with respect to cavitation.

In this case, cavitation intensity is described by a formally normalised quantity. Full calibration to the erosion rate (expressed in kilograms of metal lost per year) is possible by combining with

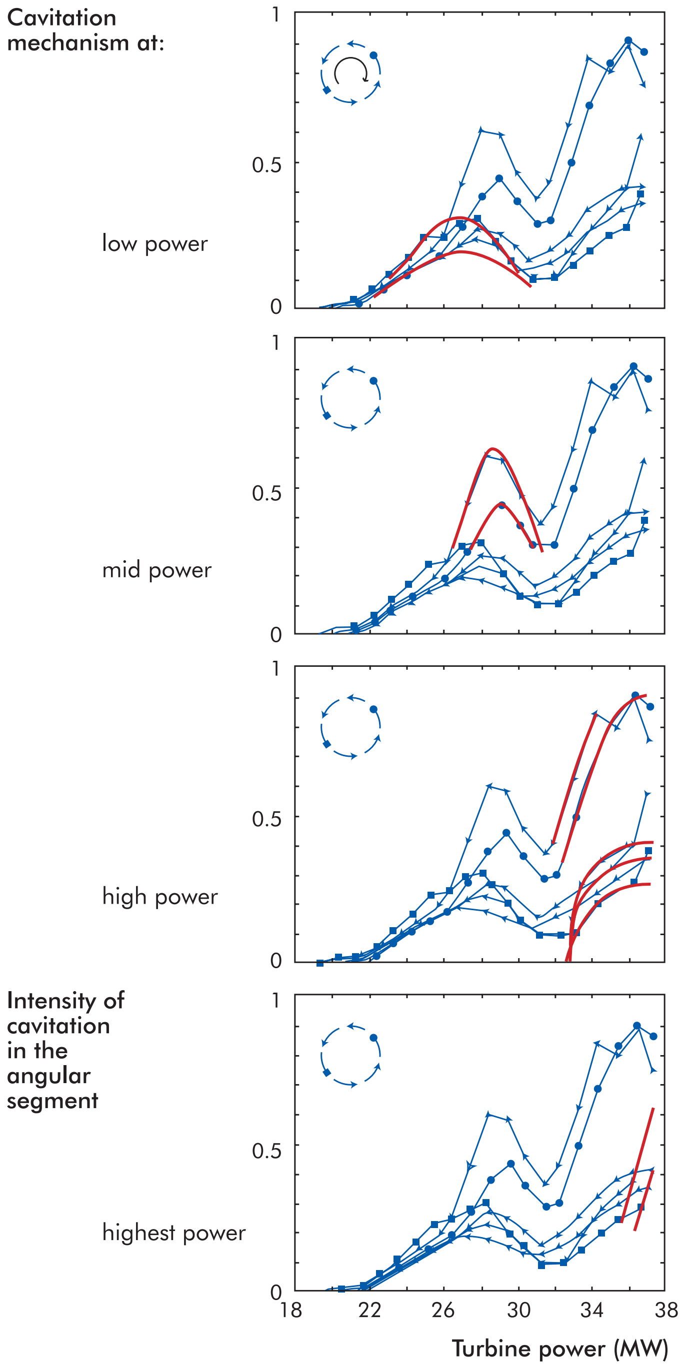


vibro-acoustic data, turbine power statistics and data on earlier cavitation damage repairs.

FURTHER ANALYSIS: CAVITATION MECHANISMS

Multidimensional analysis makes it possible to reveal the spatial distribution of cavitation within a turbine, which often yields useful further insight into cavitation process. An example is shown in figure 4. While the total cavitation curve in figure 3 only shows that the process might have a complex structure, in figure 4 the curves with spatial resolution, accompanied by some further pieces of information, enable decomposition of the total intensity into contributions from different cavitation mechanisms.

Below: Figure 4 – Decomposition of the cavitation curve in figure 3 into contributions from six angular segments in the turbine, presented here by six symbols, reveals the existence of four cavitation mechanisms in the turbine (represented by the red lines).



It is worth noting that the highest-power mechanism would stay unnoticed without the spatially resolved data.

If a general insight into cavitation in bulb turbines is combined with the diagnostic data and other results of the multidimensional analysis, as well as the model test results (in this case carried out by Turboinstitut, Ljubljana, Slovenia), the following conclusions can be made regarding the cavitation behaviour of Dubrava A:

- *At a typical head value*, *the cavitation threshold* (within the usual operating range 18-38MW) lies at a power setting as low as 22MW.
- *At low load there is hub cavitation* (low power mechanisim in the figure).
- *At the turbine efficiency optimum*, cavitation is weak or almost non-existent.
- *The cavitation optimum is narrow*. Below and above it, inlet edge cavitation on the suction side of the runner blades combines with the tip clearance cavitation (the mechanisms at mid and high powers).
- *The highest-power mechanism* causes fully developed sheet cavitation on the suction side.

The differences in cavitation intensities in various angular positions within the turbine stem from the low-pressure region in the top locations. The runner rotates clockwise and the cavitation extremes generate strong noise and erosion at the locations in which cavities disappear (ie in the regions shifted clockwise from the vertical).

Role of turbine parts

Cavitation intensity can be decomposed into components related to particular guide vanes and runner blades by multidimensional analysis of data (suitably measured, processed in time and frequency domains, and reduced to the deterministic description of intrinsi-

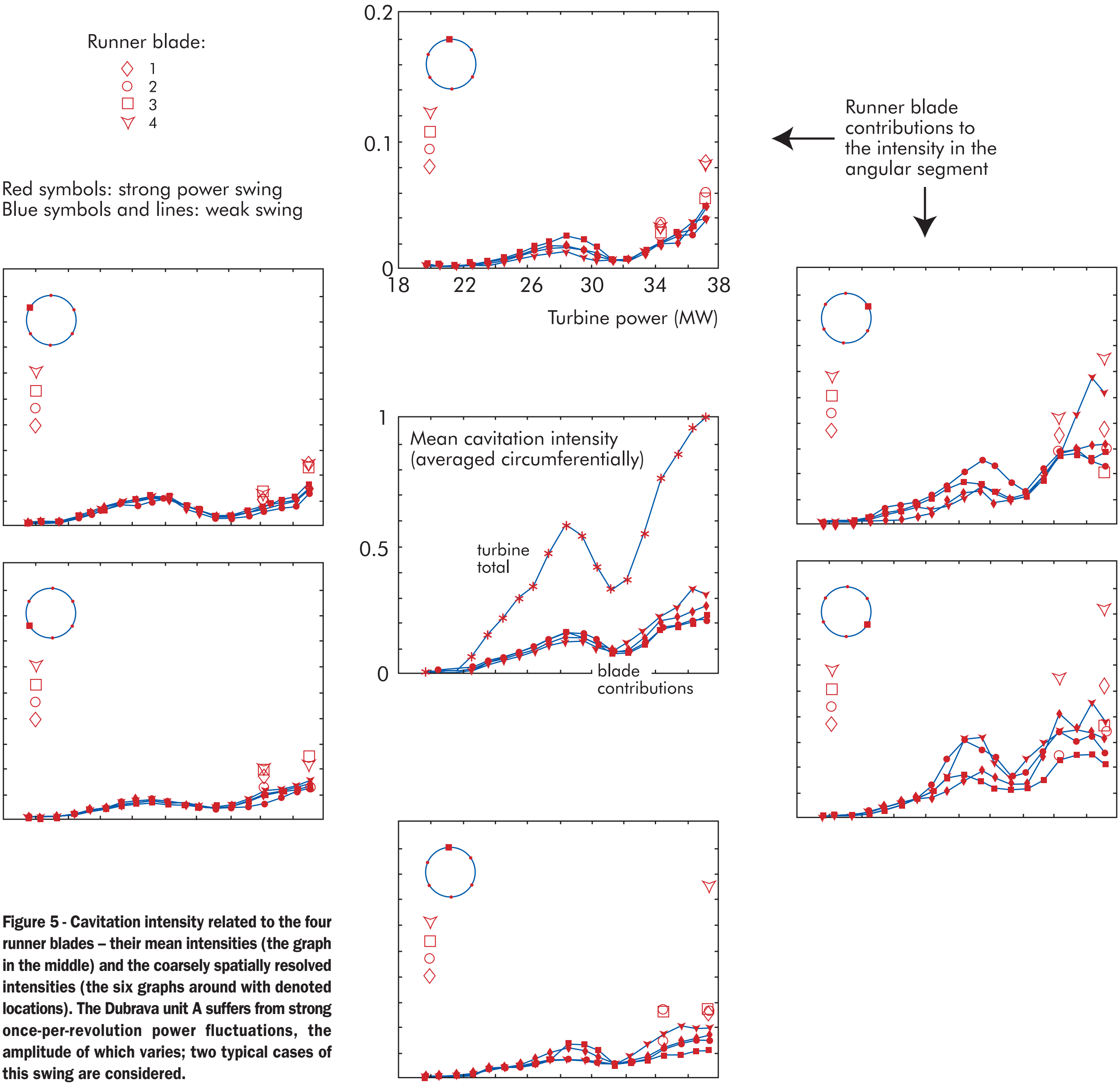


Figure 5 - Cavitation intensity related to the four runner blades – their mean intensities (the graph in the middle) and the coarsely spatially resolved intensities (the six graphs around with denoted locations). The Dubrava unit A suffers from strong once-per-revolution power fluctuations, the amplitude of which varies; two typical cases of this swing are considered.

cally random raw input). This must account for the influence of turbine loading, instantaneous angular position of the runner, and spatial position of the sensor.

By performing such a decomposition and analysing the result, one obtains directly interpretable final data in various useful formats. These describe total cavitation intensity or intensity of a single cavitation mechanism, and present these quantities in total, or in the form of components related to runner blades and guide vanes or their pairs. Further, the data can be expressed with a chosen degree of spatial resolution or without it (see figure 5).

The spatial resolution is useful in this presentation. While the four runner blades seem to cavitate almost equally strongly if judged by the mean curves, the resolved analysis discovers substantial differences among them. Indeed, cavitation provoked on blade four in the low-pressure region is two or more times stronger than on the other blades.

Cavitation in Dubrava A

According to model tests at the rated operating point, there was a safety margin of 3m water column between the critical cavitation coefficient of the Dubrava A turbine (a loss of 1% in turbine efficiency) and the plant cavitation coefficient for the originally planned tail water conditions. Highly developed cavitation was observed at this operating point. However, the turbine was designed and the model tests were carried out for tailwaters 1.5m higher than was the case, as another plant was planned, but not built, immediately downstream. Further, these considerations were based on the cavitation coefficients at the axis.

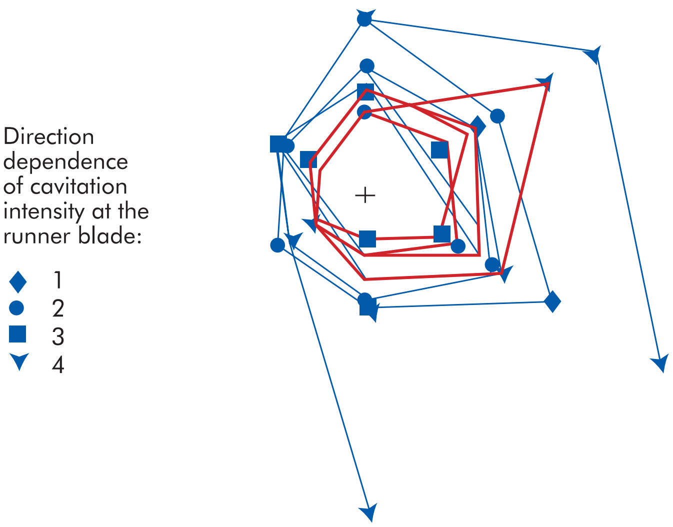


Figure 6 – Polar representation of the high-power results in figure 5. If the power swing is weak (red line curves), the four blades cavitate similarly; if the swing is strong (blue line curves), blade 4 is strongly cavitating.

The dangerous upper positions are around 2.5m higher, thus there is no reserve but instead the turbine is 1m below the critical condition. Therefore, highly developed cavitation was allowed for in the project and even increased due to the lower tail water. The appearance of the highest-power cavitation mechanism within the normal operating range of the unit (see figure 4) is attributed to this change in operating conditions.

The existence of the other mechanisms and the small width of the cavitation optimum are caused by these conditions and by the runner blade form and sub-optimal cam.

While the low power mechanism is harmless, the other three are erosive. A visual inspection of the runner revealed erosion to be traced back to each of these three mechanisms.

Stronger erosion on runner blade four was found during the inspection; this is in accordance with the results of the vibro-acoustical diagnosis (figure 5). A preliminary three-dimensional optical inspection of the runner blade geometry showed differences that might explain the exceptional cavitation behaviour of the blade. A more detailed check of the leading edge shape is recommended.

A good correlation between cavitation and the power swing (see figures 5 and 6) has been further analysed and suggests that the strong sheet-cavitation on blade four provoked by trash caught on the upper guide vanes causes strong power fluctuations. It also intensifies shaft vibration.

Improvements in the geometry of blade four would make it similar to the other blades and thus significantly improve the turbine cavitation behaviour and suppress the power swing. If the cam were optimised it should suppress the mid and high-power cavitation mechanisms. However, the overall cavitation characteristics of the turbine are not acceptable, and a substantial improvement can be obtained only by designing new runner blades adjusted to the actual tail water and having profiles less prone to cavitation and less sensitive to the inflow variations. The owner has decided to install the new blades.

Yearly statistics of power values and the data in figure 4 show that the unit is not operated in the best way to minimise cavitation. Replacing some of the frequently set power values with lower or higher values can reduce the erosion by suppressing the mid and highest power cavitation mechanisms. This will be used until a new runner is installed. IWP&DC

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The author is managing director of Korto Cavitation Services, 12, rue Ste Zithe, L-2763 Luxembourg. korto@korto.com, www.korto.com

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