

## **Low-cost revamping of the Rothenbrunnen power plant and the new technology of “forged Pelton runners”<sup>®</sup> as a key element**

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### **Introduction**

At the Rothenbrunnen powerplant of Kraftwerke Zervreila AG (KWZ) all Pelton runners were replaced between 1999 and 2000, using the solution of FRAVIT's „forged Pelton runners“<sup>®</sup>. Thanks to the successful replacement of the runners, KWZ avoided the high cost of complete refurbishment of the turbines: the new runners fit with the existing turbines, i.e. casing, injector, etc.

Several advantages in comparison with cast Pelton runners was decisive for this choice:

- the forged material has better characteristics than cast
- complete checking of the forged disk can be performed with much more ease and efficiency
- the numerically controlled (CNC) machining makes high precision possible in the realisation of the bucket profile; this has an important effect on the turbine efficiency and on the rotation of the runner
- the better material characteristics also influence maintenance and its costs. Less wear, less likelihood of cracks, lack of the typical porosities of the cast runners, which have to be welded: all these elements lead to economic advantages, which for the 30 years typical lifetime of a Pelton runner can be quite significant.

In the Power Plant the efficiency has been increased of 2.7% on average. Only with the increase in production these runners can be amortised in less than the half of the lifetime. This data have been verified by thermodynamic efficiency measurement.

After 8000 working hours no sign of cavitation is visible. The low wear confirms the expectations concerning the forged material. Moreover, by means of a continuous measurement we have confirmed that the efficiency shows no worsening.

## 1. Application of the technology of forged Pelton runner® to the refurbishment of the 7 Pelton runners of Rothenbrunnen plant

The Pelton runners of the Rothenbrunnen plant had been in service since 1957. As a result of abrasion wear, a considerable loss of efficiency was detected; to stop this trend, a complete overhaul should have been performed very soon. In Fig. 1 the efficiency curve of these runners is shown; at the highest output (38-42 MW) the efficiency showed a sudden fall.

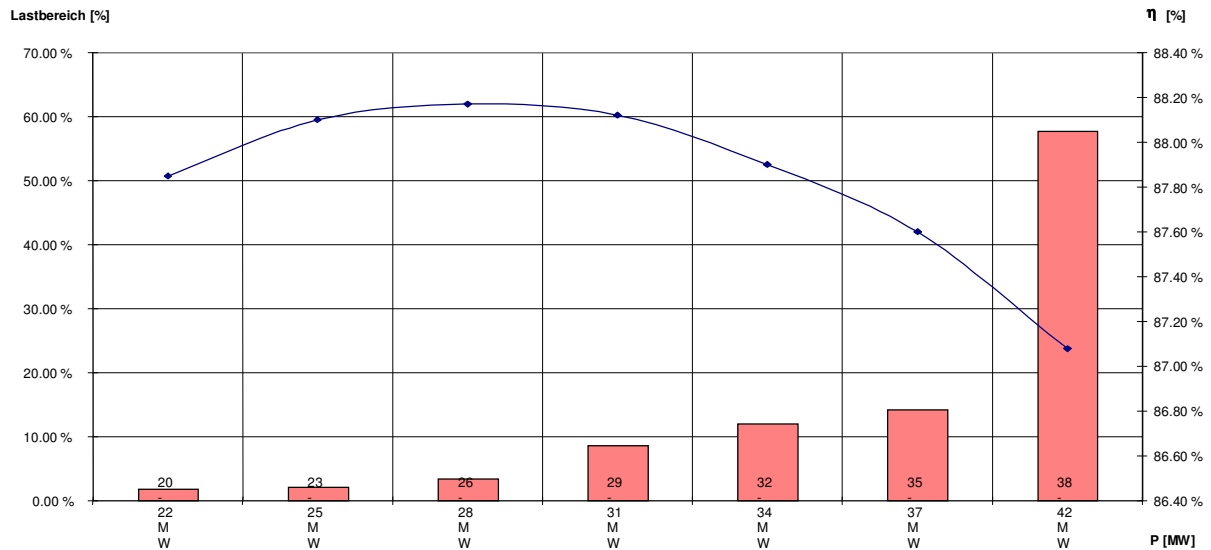


Fig. 1. Previous output rate (taken from 1.)

Because of this unsatisfactory situation, it was decided to replace the seven runners, with a view to following conditions:

- Increase in the optimal efficiency in the condition of high output
- Increase in output of 10 %, with 45 MW as a limit
- No modification to the rest of the turbine parts (such as needles, casing or servomotor)

For the renewal of the runners a new technology was chosen. The buckets are machined with high precision from a forged disk. This technology, already common for the steam and gas turbines, was applied for the first time to hydraulic turbines.

The Pelton runners machined from forged disks have three characteristics which make them different from cast runners:

- the forging process allows for very high quality mechanical properties to be obtained and materials with very few defects;
- the disk can be checked through by ultrasonic inspection (a guarantee of the absence of defects); and
- the bucket's geometry is produced by CNC milling, and therefore the position of buckets is exact.

It is clear that the problems applying to cast runners are not applicable to forged runners, with great advantages in terms of: quality, the cost of each repair and the frequency of repairs.

The advantages of the runners machined from forged disks made it possible to give to the company FRAVIT of Italy the order for two new turbine runners, with an option for a further five runners in the case of successful efficiency.



Fig. 2. CNC-Machining of a Pelton runner made from a forged disk at FRAVIT's

Soon after the two new Pelton runners were commissioned (May 1999) a thermodynamic measurement was performed. The Austrian independent Institute Verbundplan GmbH was chosen as a neutral institute. The guaranteed value of efficiency as well as of output (45 MW) was reached, with an increase of the weighted efficiency of about 2.7 %.

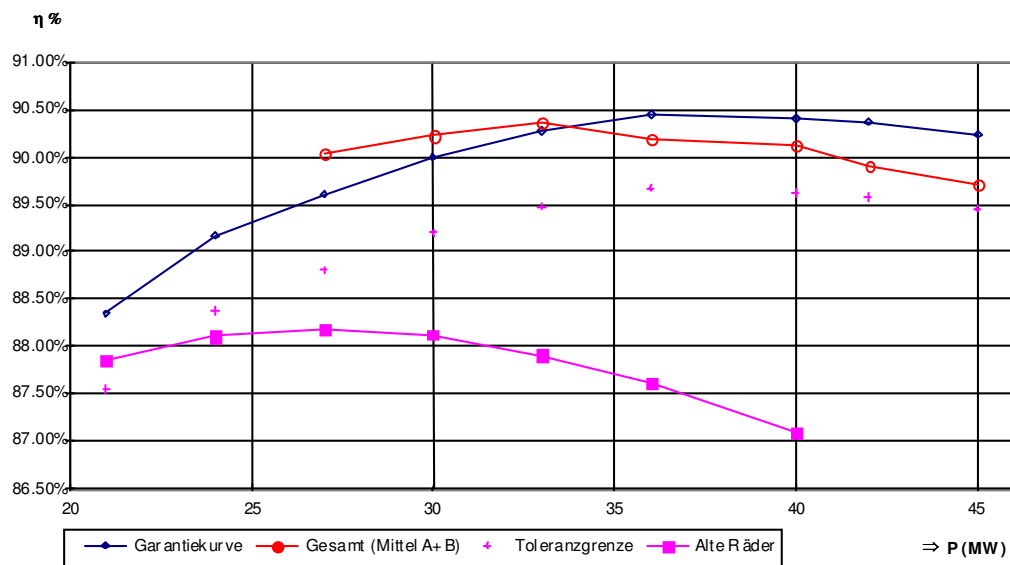


Fig. 3. Comparison between the thermodynamic efficiency of the old and the new runners of Group 2 (taken from I.)

After these positive results the next five runners were ordered, with delivery scheduled for 2000. The lifetime of the first 2 runners was 7000 hours by the end of November 2000, and no reduction in efficiency had occurred. Vibrations are minimal as the runners have almost no imbalance, and no cavitation or abrasion effects are visible. The high expectations of the Pelton runners made out of forged disks seem to be fulfilled as regards safety, long term costs and efficiency.

Furthermore, real-time measurement of the turbine efficiency allowed KWZ to monitor any reduction in efficiency due to wear, thus making it easy to decide about the repair of the runners on the basis of precise data.

## 2. The productive process

In the last few years the need to produce Pelton runners by more modern methods has become urgent, with a view to achieving better mechanical characteristics and to reduce the number of defects drastically.

The productive process of the forged Pelton runners consists of the following phases:

- Runner design
- Determination of the mathematics for the bucket profile; numerical control cutting from plate of templates for the check of sections
- Forging of the disk in heat-treated stainless steel X3 Cr Ni 13 4
- Disk rough turning with roughness Ra 1.6 for non-destructive tests
- Disk non-destructive tests – 100% ultrasonic test
- Mechanical tests in three special directions (radial, tangential and axial) on samples extracted from the disk
- Turning of runner outside profile
- Milling program – Profile milling on a resin block to obtain a bucket model and check with templates
- Numerical control machining (CNC) of bucket outside and inside profile
- Grinding according to templates
- Polishing
- Non-destructive examinations with liquid penetrant and magnetic particle inspection are not necessary anymore
- Final turning and hole boring
- Balancing

The essential instrument for this approach is CAD/CAM technology; this is fundamental to have suitable machines, equipment and software, as well as the know-how which can only result from a consolidated experience in the mechanical field.

Machining is numerically controlled and the geometries (buckets pitch, bucket symmetry as regards knife and inlet shape) are fully respected with a better distribution of stress and a better adhesion to the calculated hydraulic profiles.

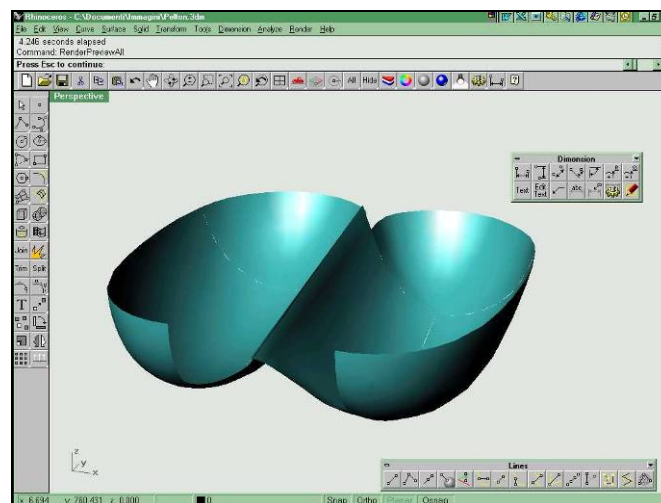


Fig. 4. Profiles study with CAD/CAM



*Fig. 5. Forged disk for a new Pelton runner*

Advantages for the Customer:

- Material with excellent mechanical properties
- Absence of defects (complete control of the material)
- Perfect geometry (bucket profiles and bucket thickness)
- Reduction in manufacturing time
- Elimination of costs/times associated with controls and repair of defects on the final product
- 80% CNC machine manufacturing – manual intervention reduction and so better quality of worker's life
- Less wear (absence of skin defects) – reduction of repair frequency: longer working time
- Future repairs – repair without problems (base lacking in porosities and foundry repairs).

### **3. Long term advantages of FRAVIT's forged Pelton runners®**

A comparison between traditionally cast runners and forged runners can be made.

There are two main problems when the runners are cast, as follows:

- The quality of the material, because of the presence of many internal defects in the runner which tend to increase under stress during its lifetime. As a result of wear, the hidden defects tend to come to the surface. The welding on a base material with defects cannot have the best possible quality, as some of the inclusions already present in the base material become part of the welded material.
- The geometry, and particularly the fact that the tangent circle of the bucket's planes is not always the same for all buckets. Thus the erosion will be slightly different for each bucket, as the discharge is not always the same. The CNC machine is able to compensate for the wrong angular division of buckets, but there is no way of compensating for the bucket's wrong position in the radial direction without affecting the hydraulics of the runner.

If the runners are forged, however, all these problems disappear, as:

- the quality of the material is the highest achievable, thanks to the complete ultrasound testing of the initial disk
- the geometry is very precise, because of the CNC-Machining of the buckets from the disk. The CNC-Program allows for reproducing the original hydraulic profile at any time, thus assuring that the guaranteed efficiency remains unchanged.

Fig. 6 shows a comparison between cast and forged runners after 8000 hours of service (the former is being checked with penetrant test in the photo). A remarkable difference in the wear effect is visible.

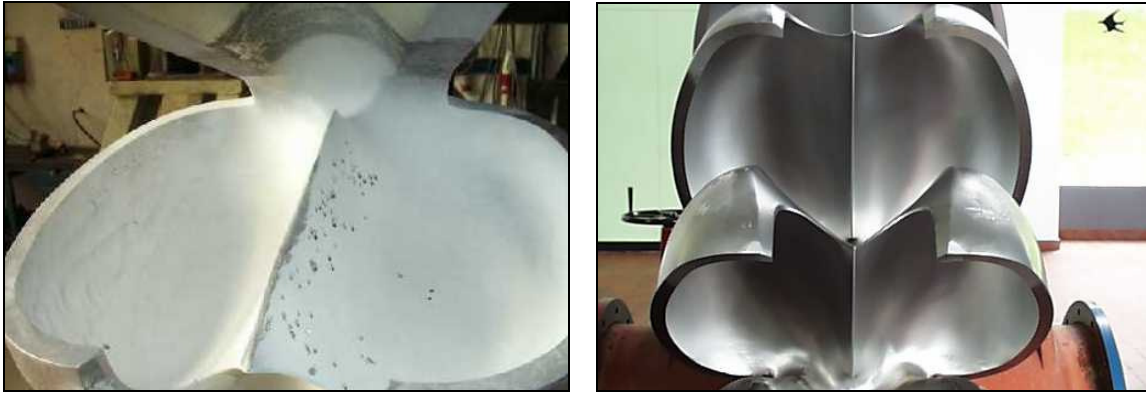


Fig. 6. Comparison between the wear in case of cast or forged Pelton runners

### 3.1 A calculation of the economical long-term advantage: the Rothenbrunnen case

The model in Figs. 7. and 8. has been implemented as a result of the co-operation of KWZ and FRAVIT to simulate and calculate the long-term economies which can be achieved by exploiting forged Pelton runners compared with the old runners (in cast version).

A major economic advantage appears from these estimations.

This means that even if the initial price of a forged Pelton runner were 25% higher than a traditional cast Pelton runner, the long-term advantage would compensate for this extra cost within 12 years. For longer periods, such as 20 or 30 years, the reduced maintenance costs would bring to an important economical advantage (not to mention the far higher safety in service, guaranteed in the case of forged Pelton runners in comparison with cast runners, and the costs linked to possible unexpected problems) .

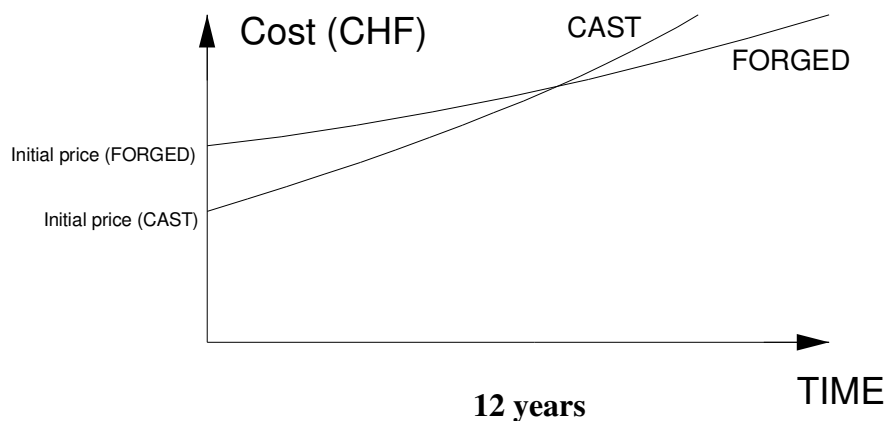


Fig. 7. Maintenance costs in case of cast or forged Pelton runner

Maintenance intervention	Maintenance cost/year (CAST)	Frequency (10 years)	Maintenance cost/year (FORGED)	Frequency (10 years)
Periodic NDT tests (PT+MT)	CHF 5'000	10	CHF 1'000	2
Small repair	CHF 1'000	5	CHF 200	1
Polishing of the hydraulic profiles	CHF 1'500	3	CHF 1'500	3
Great repair	CHF 16'000	1	CHF 12'000	1
Estimation over 10 years				
<b>TOTAL COST</b>	CHF 235'000		CHF 147'000	
Actual value	CHF 416'461		CHF 260'510	
Price of the runner	CHF 480'000		CHF 600'000	
<b>Total investment</b>	<b>CHF 896'461</b>		<b>CHF 860'510</b>	
Estimation over 20 years				
<b>TOTAL COST</b>	CHF 470'000		CHF 294'000	
Actual value	CHF 762'862		CHF 477'194	
Price of the runner	CHF 480'000		CHF 600'000	
<b>Total investment</b>	<b>CHF 1'242'862</b>		<b>CHF 1'077'194</b>	
Estimation over 30 years				
<b>TOTAL COST</b>	CHF 705'000		CHF 441'000	
Actual value	CHF 1'066'253		CHF 666'975	
Price of the runner	CHF 480'000		CHF 600'000	
<b>Total investment</b>	<b>CHF 1'546'253</b>		<b>CHF 1'266'975</b>	
Rate:		5%		

Fig. 8. Long term comparison between a cast and a forged Pelton runner

#### References

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## **The Authors**

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**Gianluca Mazza** graduated as a doctor of engineering from the Politecnico di Milano, Italy, in 1995. After participating to the rehabilitation of some Swiss powerplants, he joined Fravit in Italy, where he has been a project manager since 1997.