Lessons Learned

The Upside-Down Turbine

During an annual electric power convention, Jack, the manager of hydro production for a large utility, decided to convene an informal meeting with Ken, the engineer for a manufacturer that recently provided a new pump-turbine for one of the utility's hydro plants, and George, an engineering consultant that worked with the utility during the installation.

The reason for this meeting? The pump-turbine was not performing as expected. It was the second unit in a two-unit vertical axis, axial flow low-head station, where the level of the canal water was about midway between the low and full supply levels in the reservoir. When the reservoir was above canal level, the units acted as turbines, and when the reservoir level was drawn down to below canal level, the units acted as pumps, discharging water into the canal, after which the water flowed into the headpond of a 500-MW peaking hydro installation.

The somewhat unique pump-turbines also were designed for reverse flow from the canal into the reservoir. They had been subjected to rigorous model tests, including air tests of the complete S-shaped water passage (from the trashracks to the draft tube outlet) and hydraulic model tests of the Kaplan runner pumping and turbining in both direct and reverse flow.

The first pump-turbine was installed and performance was monitored over a complete reservoir drawdown cycle, and found to be satisfactory — well within predicted parameters.

Two years later, the second duplicate unit was installed, but performance was not within expectation. The unit was noisy and rough, with occasional vibrations; power demand during pumping was higher than expected; and turbining output was lower than expected. Unit alignment was checked, and the blade angle with respect to head verified, but no reason for the poor performance could be found. Hence Jack's decision to call the meeting to see if brainstorming could elicit an explanation for the lack of performance.

A new development

The three engineers met in Jack's suite in the hotel after dinner. About an hour into their discussion, the telephone rang. Jack answered it and listened intently. After a few minutes, he turned to George and said, "It's Mac out at the powerhouse — you had better listen! He's convinced the pump-turbine blades are installed upside down!"

Mac was well known to the three engineers. He was the chief operator for the pump-turbine and hydro plant facility, having been at the site since the start of equipment installation. He also was a skilled machinist and an avid model builder with several working scale models of steam locomotives to his credit.

He had become so fascinated with the unique shape of the pump-turbine water passages and the associated structure that he decided to build an accurate scale model from the construction and equipment drawings. Mac had been working on the model for more than three years, and it was now almost complete.

Due to the vibration and rough operation, the second pump-turbine had developed a small oil leak in the runner hub. The unit was stopped and dewatered, and Mac was inspecting the hub when he noticed that the runner blade shape did not appear to match that on his model. Puzzled, he returned home at lunch time to pick up his model. In the afternoon, he took the model into the runner chamber and carefully compared the runner prototype and model blade shape. They did not match! He was certain that he had closely followed the manufacturer's drawings when machining the blades. After more observation of the blade shapes, he noted that if he turned the model upside down, the blade configuration matched exactly. Cursing himself for making such a stupid mistake, he returned home in the evening and pulled out the runner drawings. To his surprise, his model blade shape was correct; hence, those on the prototype must be wrong. After making certain he was right, he called Jack.

After being informed of the news, Ken, the pump-turbine manufacturer's representative, reacted with disbelief. "Absolutely impossible; the runner was thoroughly inspected during manufacture and such a mistake could not occur," was his immediate comment.

The next day, a search was made through the manufacturer's photo records of the runners. Two photos were found, taken just prior to shipment. A close inspection revealed that there was a slight difference in the blades, indicating that blade reversal was a possibility.

Since the pump-turbine was designed for reverse flow with pumping head being about equal to turbining head in both directions, the runner blades were almost flat, with the trunnion placed very near the mid-blade position. However, the blade surface was more curved on one side than on the other, much like the wing profile of an aircraft, hence the reason for not detecting the mistake during manufacture.

How had the error occurred?

A review of the inspection records indicated that the blades had all been inspected, and that the dimensions were all within tolerance. By questioning the workers and reviewing the photographic records, the assembly error was found. The first runner had been assembled with the hub in the "nose down" position, as it would be installed on site. The hub rested on the small circular flat to which the nose cone would be attached. In this position, the hub was somewhat unstable, and the blades had to be supported until balance was obtained when all blades were installed. For the second runner, the assembly workers reasoned that stability of the runner hub would be improved by inverting it, so that it rested on the much wider flange that connected to the large, hollow, long shaft leading to the generator. However, they did not inform the blade fitters of the change, thinking it was obvious. The fitters proceeded to install the blades in the position required by the drawings, upside down relative to the inverted hub.

Four months were required to remove the runner, rotate the blades, and re-assemble the unit. Fortunately, provisions had been made in the design of the concrete structure for removal of the runner from below, without having to dismantle the motor-generator. Without this provision, correction of the error would have taken twice as long. Because the mistake had been made by the manufacturer, all repairs were undertaken at no cost to the utility. Tests on the corrected runner indicated performance equal to the first unit and within contracted parameters, much to the relief of all concerned.

The lesson learned

When hydraulic equipment is not performing as expected, and when the reasons for the inadequate performance cannot be ascertained through the usual tests, some consideration should be given to the more "ridiculous" suggestions as to the cause. In this particular case, Dan, the consultant's mechanical engineer in the project, had casually suggested at the third or fourth meeting with the manufacturer that perhaps the runner blades were inverted, only to be greeted with laughter. The suggestion was not pursued further. But, in the end, he was correct!

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