References

1 Yamabe, M., "Hysteresis Characteristics of Francis Pump-Turbines When Operated as Turbine," JOURNAL OF BASIC ENGINEERING, TRANS. ASME, Series D, Vol. 93, No. 2, Mar. 1971, pp. 80–84.

2 Cosma, Gh., and Anghel, A., "On Some Unstable Zones in the Operation of Kaplan-Turbines," Proceedings of the 3rd Conference on Fluid Mechanics and Fluid Machinery, Budapest, Sept. 1969.

3 Murai, H., "Oil Film Patterns and Their Relation to Characteristics of an Axial-Flow Pump at Low Flow Rate," *Journal of the Japan Society of Mechanical Engineers* (Japanese), Vol. 70, 1967, pp. 359–364.

4 Murai, H., Hirata, Y., and Mikashima, Y., "Research on Swept-Back Blades Laid Between Parallel Walls, Report 1," Reports of the Institute of High Speed Mechanics, Japan, Vol. 17, 1965/1966, pp. 185–231.

DISCUSSION

W. L. Swift[3]

The author has presented an interesting account of a type of flow phenomenon encountered at the turbine direction runner inlet edge of a reversible Francis-type pump/turbine. In this instance, model tests were used to determine the characteristics of the phenomenon and to provide corrective measures minimizing the possibility of experiencing problems on the prototype. The n_1 range in which the hysteresis loops occurred lies well within the normal operating range of the prototype, as indicated by Fig. 3 in his earlier paper [1]. This particular condition may have resulted in undesirable control instabilities, particularly during the turbine synchronizing operation.

We also have recently observed hysteresis loops in the four-quadrant characteristics of Francis-type pump/turbines. Unlike the case described by the author, these loops were never located within the range of normal turbine operation. Fig. 9 shows one quadrant of a q_1 versus n_1 plot for a Francis-type pump/turbine of specific speed = 147 (m-kw). The hysteresis loops occur to the right of the zero T_1 line, indicating that during the prototype operation this condition would be encountered only when the machine ran above steady-state runaway speed (for a given gate). One should note also that the configuration of the loop is opposite to that described by the author; i.e., the onset of inlet edge separation is associated with an increase in n_1. Although no noticeable dependence on the model cavitation factor was observed with respect to size or location of the loops, we attribute the occurrence of the loops to the same cause cited by the author; the onset of severe inlet edge separation. It would be helpful in this respect to know whether the changes in γ_1 and θ in the model C-2 completely eliminated any hysteresis occurrence or whether these changes merely moved the loops out of the range of normal turbine operation.

A study conducted by the writer of Francis-type pump/turbine models lying within the range of specific speeds of the models described in the paper has resulted in findings which differ somewhat from the conclusions stated by the author. The author shows that the alteration of sweepback θ at the runner vane entrance, outside diameter D_1 of the runner, and runner vane entrance angle γ_1 did change the configuration of the hysteresis loops and ultimately removed these loops from the normal turbine operating region with a relatively minor loss in turbine efficiency and no degradation of pump performance. However, the extension of these results to the conclusion that the determination of a runner vane shape having no hysteresis characteristic is solely a result of the choice of values for these parameters does not agree with the writer's findings. In the general case, the onset of inlet edge separation and hysteresis in the four-quadrant characteristic will be governed by the entire cascade geometry in conjunction with the velocity distribution in the machine.

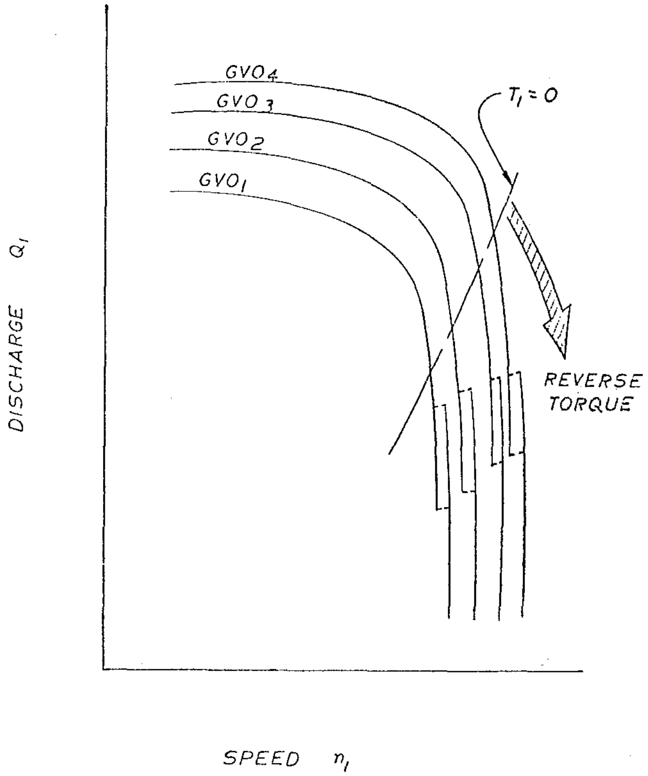

Fig. 9

Author's Closure

In this report an important influence of the entrance angle of runner vane γ_1 and the sweepback θ over turbine hysteresis characteristics was reported. It is presumed, however, other factors such as a shape of whole vane curve and a shape of flow surface at shroud and crown have subtly to do with it. As the occurrence of hysteresis is caused by dual nature of the flow in a runner channel, frequency of this phenomenon is invariably in proportion to the height of a runner vane (viz. the amount of specific speed). It is considered, however, that the proposed improvement is effective qualitatively where hysteresis characteristics themselves are similar even in case the main factors of the shape of a runner, such as the height and the length of a vane, are different from those of another.

The author's answer to the writer's question whether or not any hysteresis occurs in the improved runner C-2 with altered entrance angle of vane γ_1 and sweepback θ, is as follows:

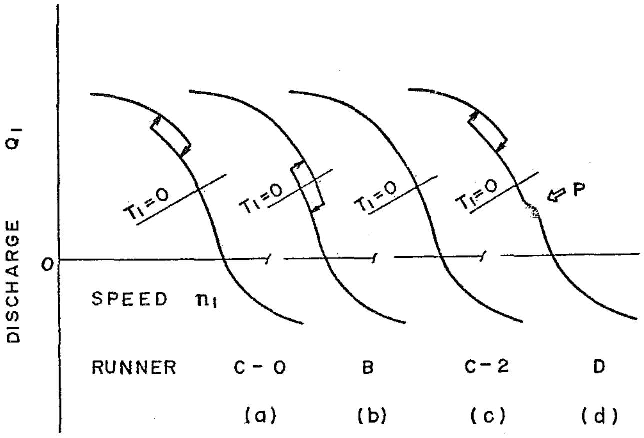

Fig. 10 Characteristics of hysteresis and stage

(Author's Closure continued on p. 704)

---

[3] Project Engineer, Product Development, Allis-Chalmers Corp., Hydro-Turbine Division, York, Pa. Assoc. Mem. ASME.

(Author's Closure continued from p. 585)

The hysteresis characteristics of the base model C-0 was generated in the domain of $\eta_t > 0$, viz. $T_1 > 0$, as shown in Fig. 7. In a pump-turbine (B) with specific speed 110 (m-kW) shown in Fig. 5 of Report [1], the hysteresis characteristics ranged to both $T_1 \gtrless 0$ at 100 percent opening of the guidevane. Both models had only one loop and no loop with counterclockwise turning as shown in Fig. 9 nor other special phenomenon was observed. And it is confirmed that no loop is engendered in any domain in the improved runner C-2. The same is confirmed too with other runners with the same specific speed 140 (m-kW) but different main sizes (B/D_1, D_2/D_1). But a slightly different characteristics are observed in model (D) with specific speed 190 (m-kW). That is, as shown in (*d*) of Fig. 10, clockwise hysteresis is engendered at $T_1 > 0$, while a slight stage characteristics were observed on the characteristic curve at *P* where $T_1 < 0$ in model (D). However, no sudden change was observed at this point and no hysteresis existed. And in the D-1 runner which is D improved by our method, it was confirmed that no hysteresis occurred in the range of $T_1 > 0$, but whether there exist any stage characteristics or not has not been confirmed.

The cause for generation of stage characteristics observed in the neighborhood of *P* in Fig. 10 (*d*) and hysteresis characteristics in Fig. 9 has not been certified. Investigation was made on the flow distribution at the runner exit in the neighborhood of *P* in Fig. 10 (*d*), but no particular change was found. In that operation, however, water in the neighborhood of the exit of runner shroud became a strong swirling flow and water in the neighborhood of the runner crown showed a strong tendency to reverse flowing under centrifugal effect, thus the flow having been made very complex. As a result, it is difficult to tell how much the vane shape at the entrance of turbine has affected those phenomena. It is an interesting question to be studied in future for us to pinpoint the part of a runner a flow from which is influencing those phenomena.