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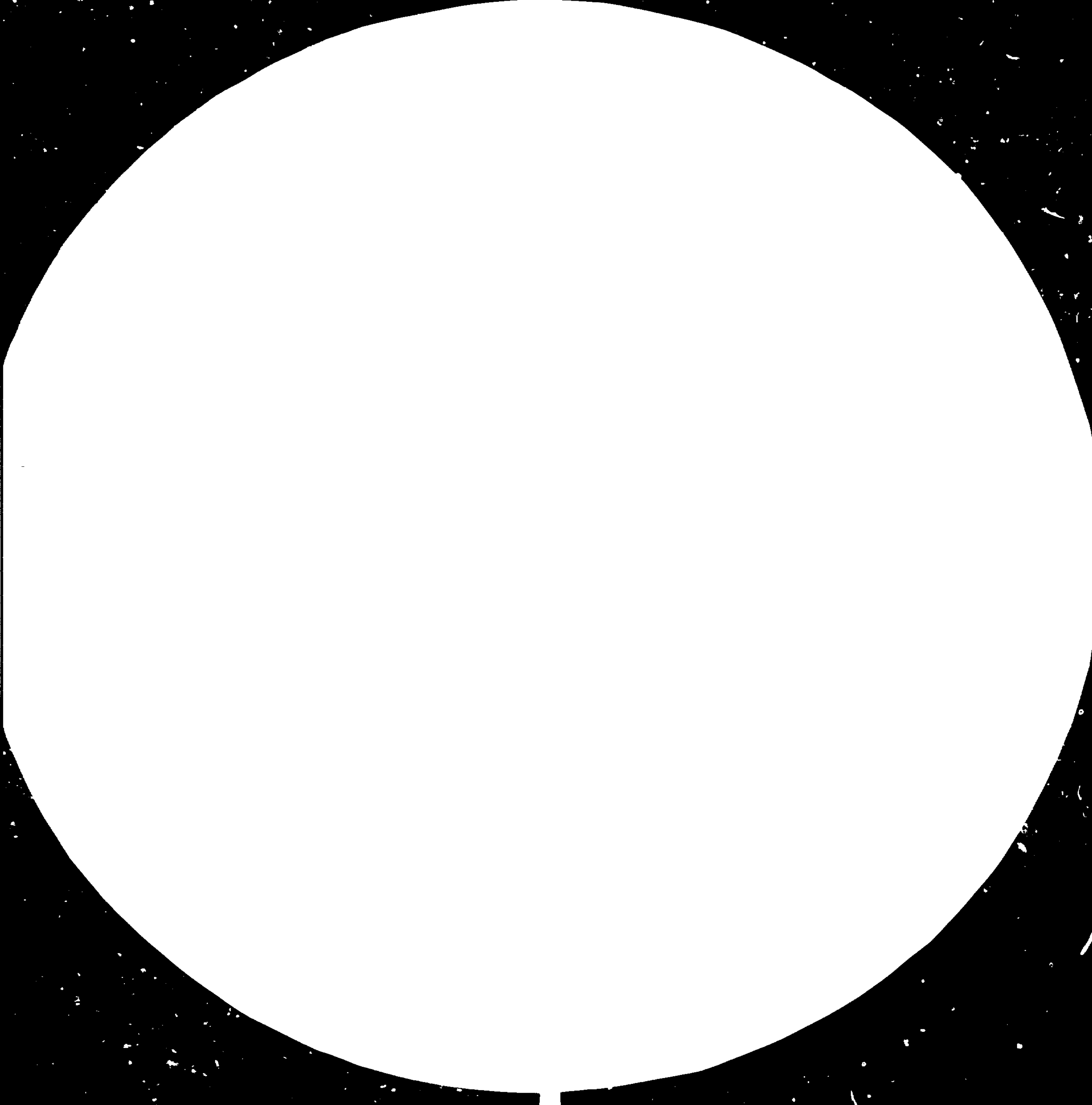

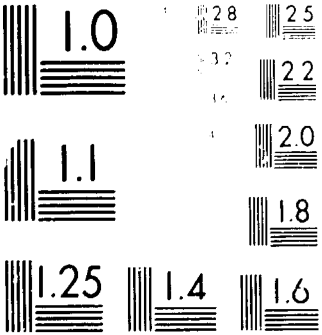


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# APPLICATION OF RELIEF VALVES IN SMALL HYDROELECTRIC STATIONS*

by


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*In this article authors describe a relief valve with a novel all-oil control system and its application conditions in small hydroelectric stations.*

**Introduction**

As the load of a hydroelectric unit is rejected suddenly during operation, the governor automatically causes the turbine to close its guide vanes rapidly, and consequently produces the penstock pressure rise $\zeta$ and the turbine speed rise $\beta$. $\xi$ and $\beta$ can both be expressed as functions of the principal variable Ts, the closing time of guide vanes. It is known from the characteristics of the penstock and the turbine that $\zeta$ will vary contrary to $\beta$ for a certain range of variation of Ts, that is, when Ts increases, $\zeta$ will decrease, while $\beta$ increases, and vice versa. For a hydroelectric station with short penstock (normally the starting time of penstock Tw is less than 2.5 seconds) reasonable values of $\zeta$ and $\beta$ can be obtained if Ts is selected properly. But for a hydroelectric station with long penstock it is often impossible to select an appropriate value of Ts that will make both $\zeta_{max}$ and $\beta_{max}$ fall within allowable ranges. In such a case, a surge shaft (or surge tank) is usualy installed to ease the contradiction between $\zeta_{max}$ and $\beta_{max}$, thereby ensuring stability of the regulation system. This arrangement actually shortens the effective length of the penstock and reduces the value of Ts within allowable limits. But by employing surge shafts, high costs of construction will be involved and larger amounts of building material and longer constructiontime will have to be spent. Moreover, for some sites surge shafts are difficult to construct owing to poor topographical and geological conditions. In order to cut down capital investment and speed up construction, a scheme of replacing the surge shaft with a relief valve employing a novel all-oil control system was developed. From the characteristic tests for a single relief valve at Jingganshan Hydroelectric Station of Jiang Xi Province and also from the industrial tests and four years of operating experiences at Longyuan Hydroelectric Station, Hunan Province, it has been shown that the application of Type TFW-400 relief valves with all-oil control systems in place of a surge shaft is successful. The pertinent facts of the scheme are:

Total length of tunnel plus penstock 1950 m
Head 83 m
Capacity of Unit 1600 kw

In case of rejection of full load for three units the penstock pressure rise $\zeta$ is 14.5% and the turbine speed rise is 24.4%. These values are appreciably lower than those for a design employing surge shaft ($\xi$ = 24%, $\beta$ = 32%) and are very close to the values obtainable under optimum closing low. i.e., $\zeta = 11.2\%$, and $\beta = 25.5\%$. The stability and transient process quality under conditions of no-load and on-load disturbance for the turbine regulating system also met requirements of the power station. A saving in cost of 90% of that of a surge shaft was realized in addition to the commissioning of the power station one year ahead of schedule.

## I. Type TFW-400 Relief Valve with All-oil Control System

The action of the relief valve must be sensitive, safe and reliable when it is used in place of a surge shaft in hydroelectric projects. Most relief valves used in the past were of the mechanical type, and these have been proved by experiences over the years to be unreliable, and the action of the relief valve would also lag behind that of the guide vanes by up to 0.5 second. Consequently, though a relief valve was installed in the hydroelectric station, the penstock pressure rise would still be very high. Special safety measures would still have to be taken to protect the penstock in case of relief valve failure. Therefore, the mechanically controled relief valve could not completely attain the function of reducing water-hammer. Various designs of relief valves with hydraulic control systems were developed in later years. Though their performances were somewhat improved, shortcoming were still quite evident. For examples, some valves still retained a time lag of 0.1-0.4 second; some valves required an increase of the capacity of turbine pressure oil system; while still others had complicated systems comprising large numbers of control elements that were difficult to adjust on site, and so forth.

The above mentioned shortcomings have all been overcome in the Type TFW-400 relief valve. The valve proper and control system are described separately as follow:

The construction of the valve proper (see Fig. 1)

The Type TFW relief valve is of horizontal arrangment, and consists of valve casing 1, valve disc 2, balancing chamber 3, main servomoter 4, pilot oil chamber 5 and water inlet and drainpipe, and air supply valve, etc. The main servomoter and pilot oil chamber are connected integrally with the valve casing to attain small size, simple construction and compact arrangment.

The cast steel valve casing is made up of two partial spiral shaped duct symmetrical to the vertical center line. Stay vanes in the valve casing will turn the incoming water into vortex flow, thus achieving effective energy dissipation before the water is discharged into the tail race. The valve is equipped with an air supply device to reduce vibration during operation.

The valve plugs may be conical or round. They are made of cast steel with surfaces plated with chromium for rust prevention. Several balancing holes are provided on the valve plug to reduce operating pressure.

Sealing of the valve is accomplished by the close contact between the stainless steel overlaid seal ring on the valve plug and the removable phosphorous-bronze seal ring on the valve body. These two surfaces are precisely fitted by grinding to give satisfactory sealing.

The control system of the relief valve (see Fig. 2)

The main feature of the relief valve control system is the employment of pressure oil for direct and complete control and operation. It also has a two-step closing device for the guide vanes.

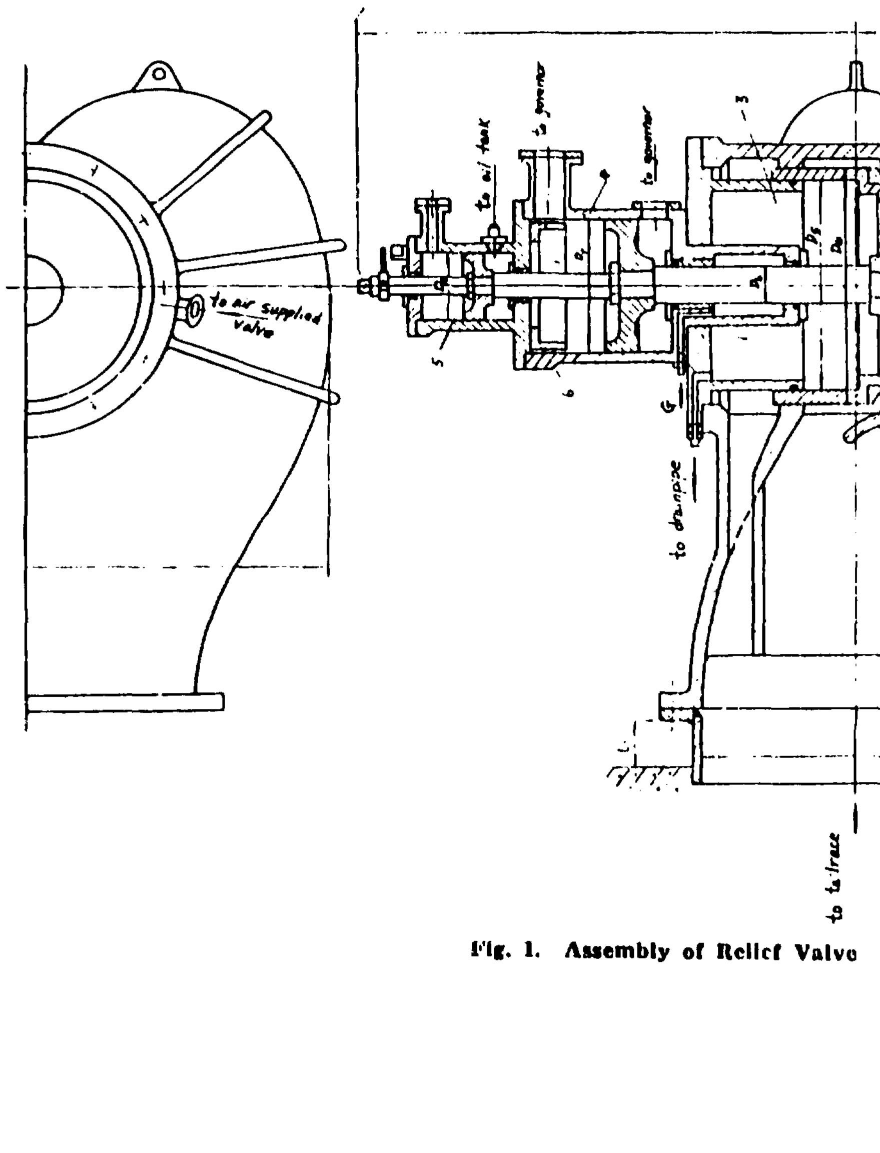
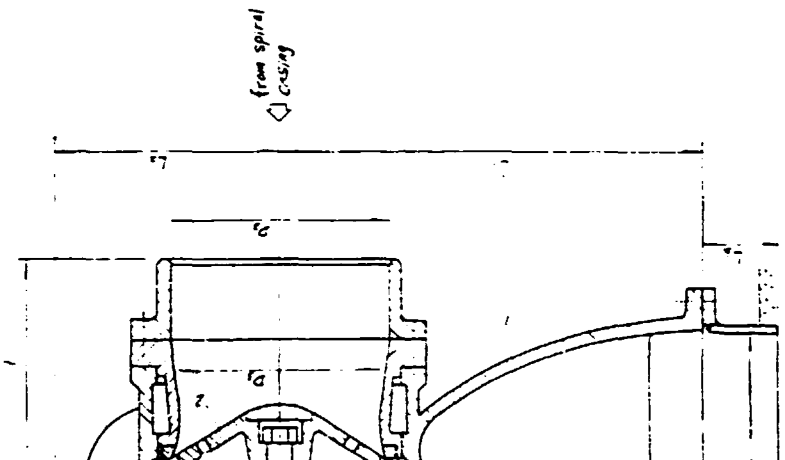



**Fig. 1. Assembly of Relief Valve**



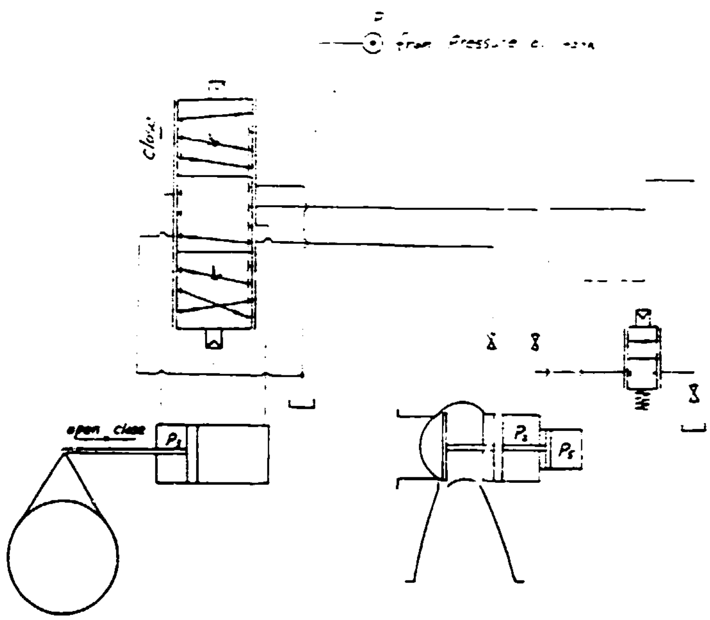



**Fig. 2 Diagram of control system**

The principle of action of the control system is as follow:

1. When the turbine load is constant, the piston of the main distributor is at the middle position and the oil under pressure $P_1$ flows into the closing chamber of the relief valve via throttle hole, while the opening chamber is conneted to drain. Because the oil pressure in the closing chamber is higher than the water thrust on the valve disc, the relief valve remain in the closed position.

2. When the turbine load reduces by a small amount (within 15% of rated output), the main distributor moves upward only a small distance, so that a limited amount of oil under pressure $P_1$ enters the closing chamber of the main servomotor to make the guide vanes close slowly, while the relief valve remains closed.

3. When more load is rejected momentarily (greater than 15% of rated output), the upward motion of the main distributor piston is now much greater, then the relief valve opens quickly at the same time the guide vanes close. The action of the two is synchronized with zero time lag.

4. As the turbine load increases, the oil under pressure $P_1$ flows directly into the opening chamber of the main servomotor, so the relief valve remains at the closing position.

5. "Stepped closure device": This device is thrown in when the relief valve starts to fast open, the relief valve accelerates to the position determined by the limiting ring and then proceeds at a lower speed, thus causing the guide vanes to close in two stages. The break point of the two-step device can be easily adjusted on site.

Should the relief valve fail to work, the guide vanes have to be closed slowly, to ensure that the penstock pressure rise will not exceed allowable limits.

## II. Stability and Transient Process Quality of the Turbine Regulating System Employing Relief Valve

When using the relief valve. the following problems are of great importance:

1. Calculation of the maximum penstock pressure rise $\zeta_{max}$ and the maximum turbine speed rise $\beta_{max}$ when load is rejected.

2. Calculation of the stability and the transient quality of the turbine regulating system when small disturbance occur.

For many years the practice has been to compute the two aspects of the problem separately. That is ,in the case of load rejection methods such as the Allievi formula was used for the calculation of the maximum penstock pressure rise $\zeta_{max}$ and methods such as the S.M.S. formula for that of the maximum turbine speed rise $\beta_{max}$; whereas, in case of small load disturbance. the stability and transient quality calculations were carried out by simplifying the original high-order regulating system to a third-order system consisting of a Pelton turbine, an ideal governor and rigid-column water hammer. Obviously, this method of calculation will not be suitable for the case of a hydroelectric station with a long penstock and a relisf valve.

The present study treats the transient process of the regulating system on the basis of modern control theory, and integrates the calculations for large perturbations and for small perturbations. It takes into account the non-linerarity of the turbine elements and some important nonlinear factors of the governor, such as the saturation characteristic of frequency measurement device, stroke limit of dashpot, dead band and stroke limit of the main distributor and main servomotor, accurate results on both regulation guarantee and stability as well as transient quality calculation may be obtained simultaneously.

The block diagram of the turbine regulating system with Type TFW-400 relief valve is shown in Fig. 3.

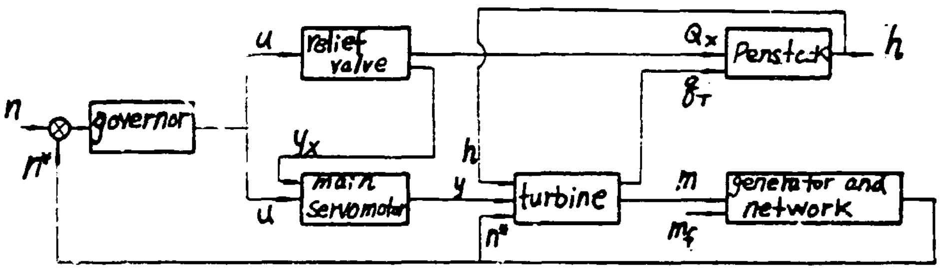



**Fig. 3. Block Diagram of Turbine Regulating System**

According to fig. 3 and the above mentioned principles. three types of calculation for three unites at the Longyuan Experimental Hydroelectric Station were performed for simultaneous load rejection, load perturbation and determination of stability range. The pertinent technical data are as follows:

Type of turbine: HL638-WJ-60

| | |
|---|---|
| Head | 69 m |
| Flow | 2.0 $m^3/s$ |
| Output | 1184 kw |
| Speed | 1000 r. p. m. |

| | |
|---|---|
| $GD^2$ | 2-3 T-m$^2$ |
| Type of relief valve | TFW-400 |
| Sx max | 80 mm |

The calculated and experimented results are seen to be in good agreement, as in Figs. 4, 5.

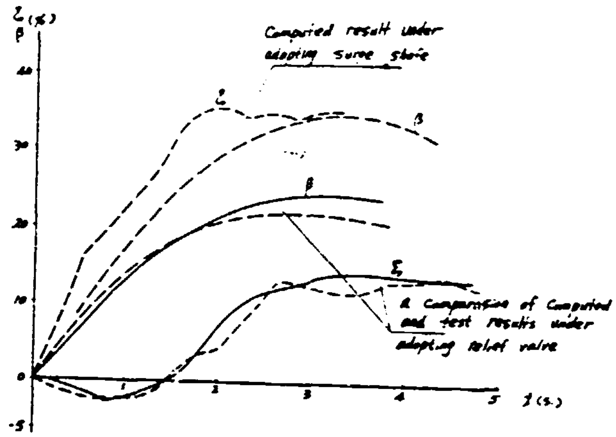



**Fig. 4. A Comparision of Test and Computed Results in case of Rejection of full load for Three units.**
**— test result ----Computed result.**

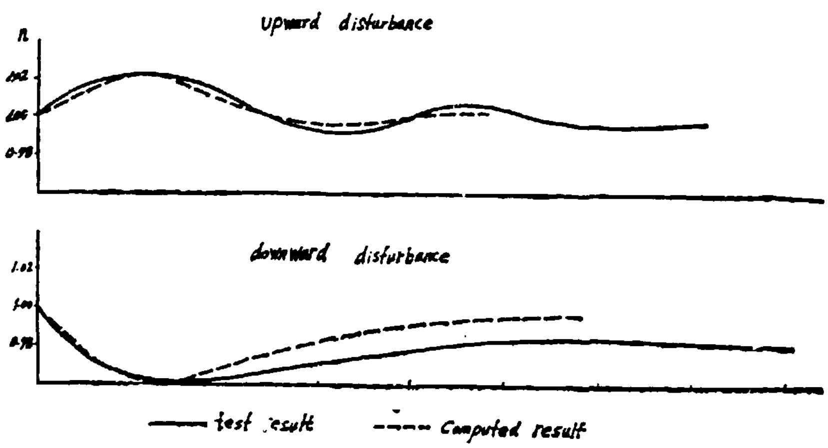



**Fig. 5. A comparison of Test and computed results**

The units run smoothly when they are connected to a large network, but when each unit carries an isolated load, the stability under small perturbations mainly depends upon the performance of the governor. the larger the penstock, the higher the performance demand of the governor. Therefore, when making the choice of using relief valves instead of a surge shaft, emphasis should be put on the technical requirement of the governor according to the actual conditions of the given hydro-electric station. Fig. 6 shows the relative stability of a case using relief valve as compared to that with a surge shaft for a unit equipp with Type XT-600 governor (mechanical type) when operating isolated.

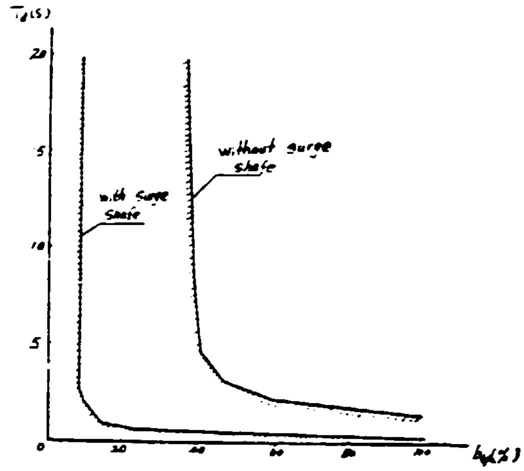


Fig. 6. Stability Range of Turbine Regulating System on Isolated Nctwork.

## III. Serial Design of the Relief Valve and Its Apllication

After the initial three sets of TFW-400 relief valves with all-oil control system were successfully put into operation early in 1976 at Longyuan Hydroelectric Station, Hunan Province. Serial designing of the relief valve for different types of turbine and of various sizes were under way. Seven models for various head ranges comprising four diameters (∅400, ∅500, ∅800, ∅1000, mm) were designed. Main data are as in table 1. The range of application of the various releif valves are shown in Fig. 7

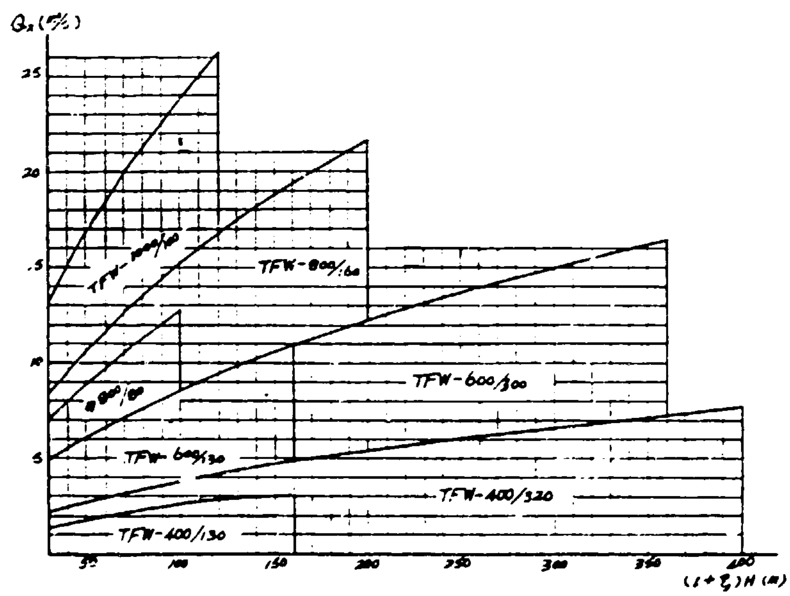



Fig. 7. Range of operation of various type of Relief valves

| Items \ Type | TFW 400/130 | TFW 400/320 | TFE 600/130 | TFW 600/130 | [illegible] 800/80 | TFW 800/100 | TFW 1000/160 |
|---|---|---|---|---|---|---|---|
| Diameter Dx (mm) | 400 | 400 | 600 | 600 | 800 | 800 | 1000 |
| Max. Stroke, Yx (mm) | 80 | 100 | 150 | 150 | 200 | 200 | 250 |
| Nominal Head, Hp (m) | 130 | 320 | 130 | 300 | 80 | 160 | 100 |
| Max. Head $H_{max} = (1 + \xi)$ Hp (m) | 160 | | 160 | 360 | 100 | 200 | 120 |
| Max. Discharge Qx ($M^3$/sec) (at Max. Head) | 3.15 | 7.67 | 10.9 | 16.4 | 12.8 | 21.7 | 26.3 |
| Remarks | conical valve plug | round valve plug | round valve plug | round valve plug | conical valve plug | round valve plug | round valve plug |

More and more projects came to use relief valves in place of surge shaft after the successful experience at Longyuan. Up to the present, relief valves at a number of stations, such as Jinggangshan (Jiangxi Prov.), Changtanhe (Guangxi Prov.) and Jixi (Fujien Prov.) have been put into normal operation successively. Another 17 hydroelectric stations have been supplied with 33 relief valves. And still 13 more stations are in the planning stage to use a total of 30 relief valves.

A saving of investment of more then 5.4 million yuan has been achieved from the adoption of relief valve in place of surge shafts at these hydroelectric stations. Besides, the above saving does not include cases where topographic and geological conditions do not permit the construction of a surge shaft, hence, the investment is difficult to estimate.

## IV. Discussion

1. The relief valve with all-oil control system exhibits advantages in sensitive action, (with no time lag) safety and reliability, simplicity in structure, convenience in adjustment and maintenance. A hydraulic interlock is built between the relief valve servomotor and the turbine servomotor to allow accurated in synchronization that will be free from multifunctioning thus affording added safety to the penstock and the turbine. The "stepped-closure" device permits the selection of better parameters of regulation values of $\xi$ and $\beta$ can be determined from two independent time constants i.e. the value of $\xi$ from the turbine slow closing time $T_s$, while the value of $\beta$ from the fast closing time $T_m$.

2. Because the relief valve with this control system will not act in case of small perturbations, it is important to note that when selecting governor for a hydroelectric station equipped with relief valve. the governor temporary speed droop it, time constant of the damping device Td and other related parameters should have the largest range of adjustment possible.

3. Because of the difference between the flow characteristic of the turbine and of the relief valve, a perfect match is difficult, with the result that a pressure

depression often takes place at the initial interval of guide vane closing and at the end interval. Uniform variation of flow in the whole penstock system can be attained by rational selection of opening — closing law of the relief valve and guide vanes. Pressure depression may be retarded or avoided.

**Table II. Station with R.V. in Operation and Under Construction**

| Station | No. of units | unti capacity KW | Design head M | Type of R.V | Year of delivery |
|---|---|---|---|---|---|
| 1. Jinggang-Shan (Jiang Xi) | 2 | 1600 | 28 | TFW-400 | 1974 |
| 2. Longyuan (Hunan ) | 3 | 1600 | 83 | TFW-400 | 1975 |
| 3. Changtanhe (Guang Xi) | 2 | 2000 | 105 | TFW-400 | 1979 |
| 4. Dong-fang-hong (Xinjiang) | 2 | 800 | 45.5 | TFW-400 | 1979 |
| 5. Jixi (Fujian ) | 4 | 800 | 30 | TFW-400 | 1979 |
| 6. Sandache (Hubai ) | 2 | 600 | 30 | TFW-400 | 1979 |
| 7. Changtan (Sichuan) | 2 | 500 | 40 | TFW-400 | 1979 |
| 8. Sifangchi (Sichuan) | 4 | 1250 | 40 | TFW-400 | 1979 |
| 9. Diaoda (Jilin ) | 3 | 200 | 190 | TFW-400 | 1979 |
| 10. Xiaoyishan (Jilin ) | 2 | 630 | 23 | TFW-400 | 1979 |
| 11. Longtan II (Ningxia) | 3 | 630 | 52 | TFW-400 | 1979 |
| 12. Shuihu dong (Hebei) | 2 | 1600 | 89 | TFW-400 | 1979 |
| 13. Dajiangdong (Hunan) | 2 | 1600 | 165 | TFW-400 | 1979 |
| 14. Xierhe II (Yunnan) | 4 | 12500 | 109 | TFW-800 | 1979 |

**References:**

1.郭中兴，戴君年：“湖南省龙源水电站用调压伐代替调压井的研究与实践”
《水利电力技术》1979年 第一期

2.沈宗树，钟承纲：“混流式水轮机调节系统动态特性分析”
《水利电力技术》1979年 第六期

3. H. Brekke:
Stability Studies for a governed Turbine Operating Under Isolated load Conditions.
"Water Power" No. 9, 1974

4.克里夫琴柯张昌龄译：“水力发电厂的水锤及水轮机合理调节程序”
北京电力工业出版社 1956年

5.秋元德三著：“水击作用と压过脉动”
日本工业新闻出版社 1972