PUBLISHED
MAY 11, 1943.
BY A. P. C.

P. GILLI
STEAM POWER PLANT WITH HEAT ACCUMULATOR
Filed April 3, 1937

Serial No.
134,706
4 Sheets-Sheet 1

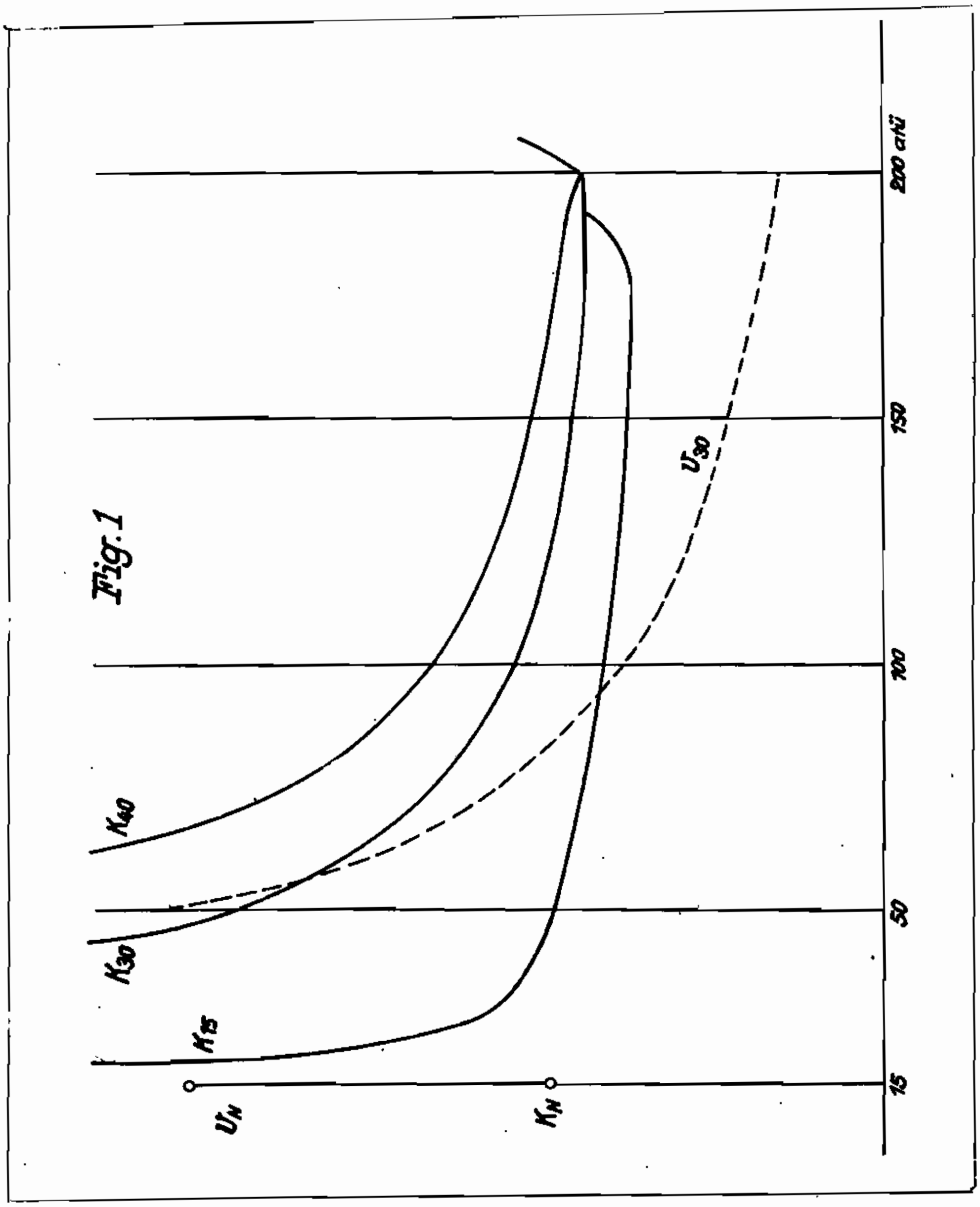

Fig. 1

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PUBLISHED | **P. GILLI** | **Serial No.**

MAY 11, 1943. | **STEAM POWER PLANT WITH HEAT ACCUMULATOR** | **134,706**

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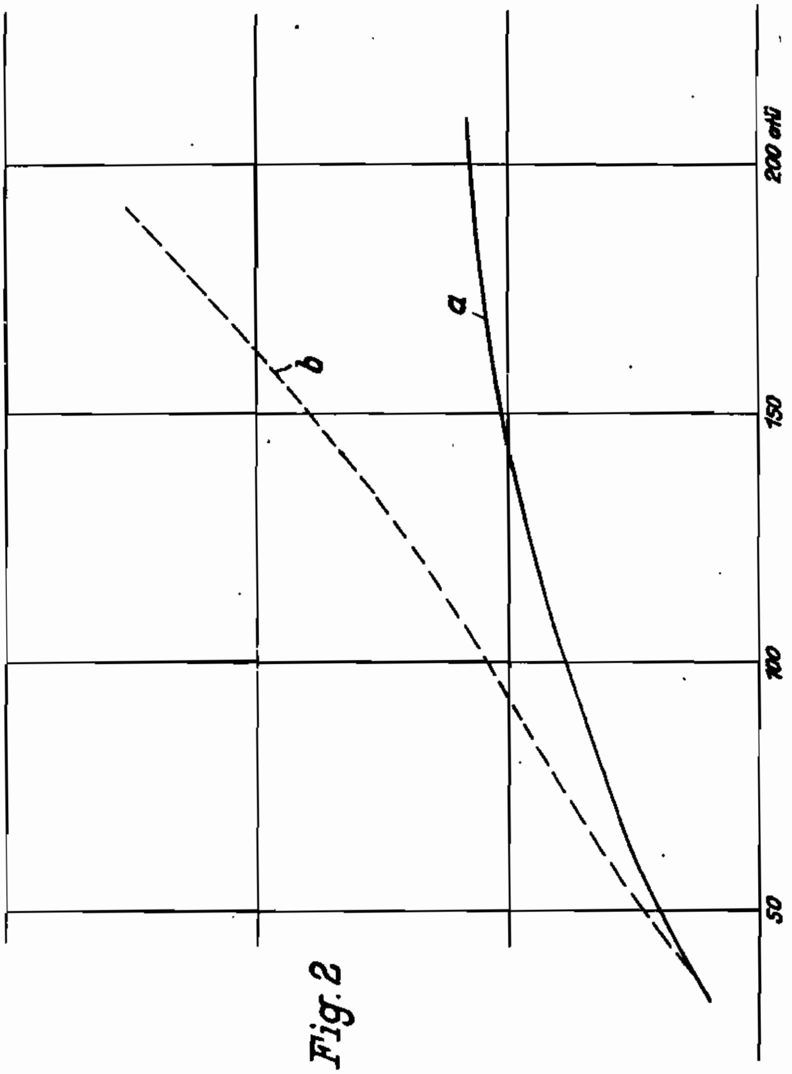

Fig. 2

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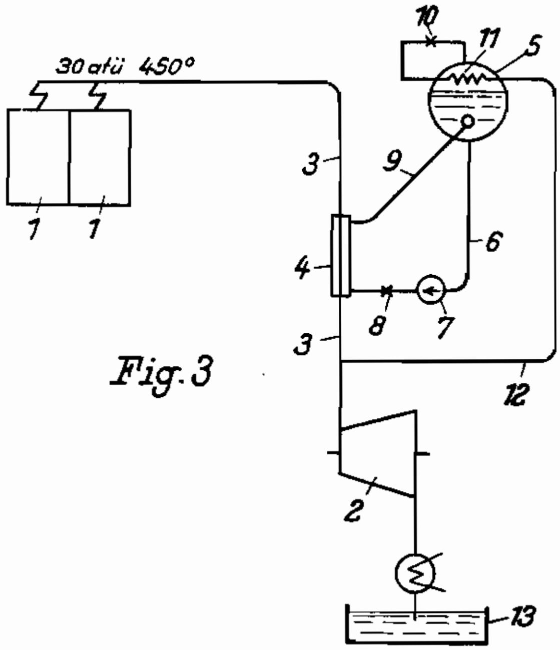

Fig. 3

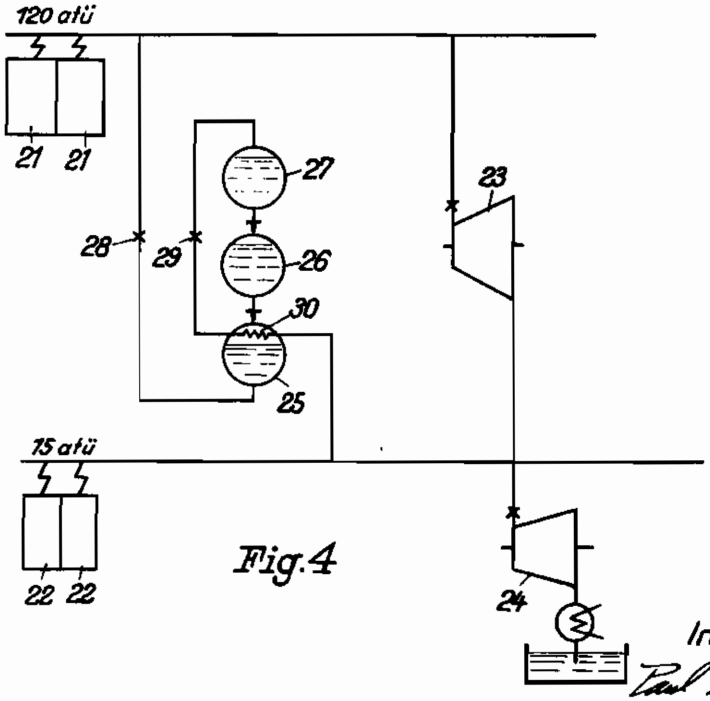

Fig. 4

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Fig. 5

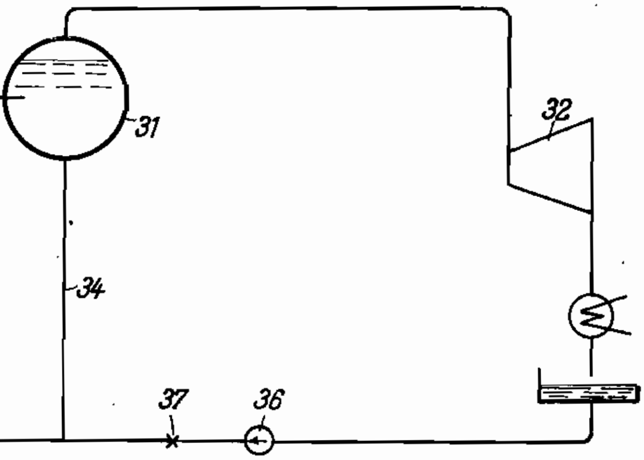


Fig. 6

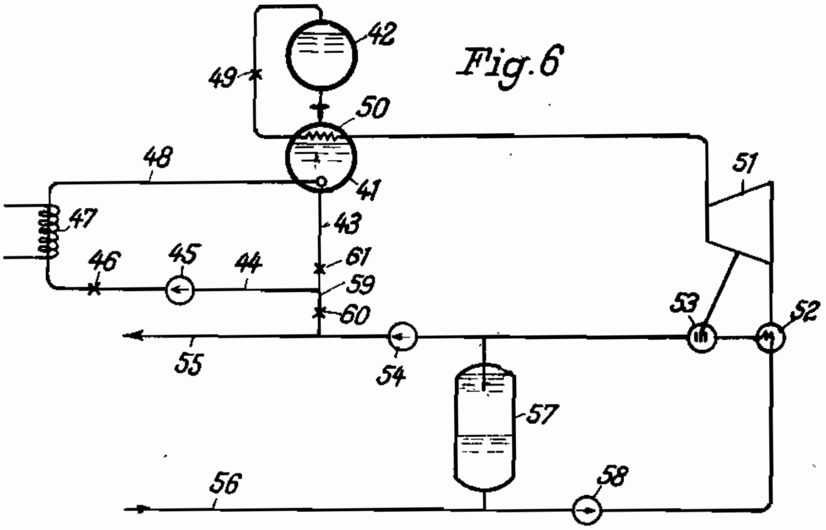
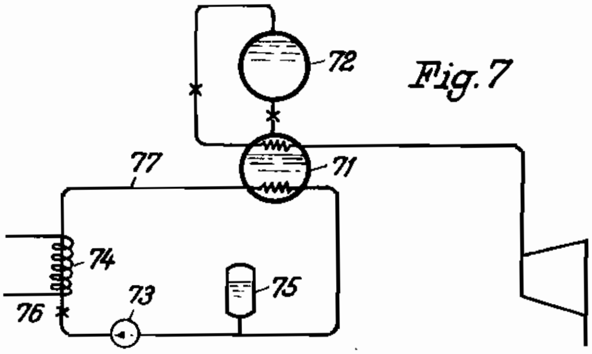


Fig. 7



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Published May 11, 1943 **Serial No. 134,706**

ALIEN PROPERTY CUSTODIAN

STEAM POWER PLANT WITH HEAT ACCUMULATOR

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Application filed April 3, 1937

The invention refers to steam power plants, for example power stations, with one or several heat accumulators, filled either entirely or partly with water, and from which steam is taken for operating a prime mover. The pressure of the accumulator plant drops when supplying steam, and increases again when the accumulator plant is charged. Thus the accumulator pressure fluctuates between a maximum pressure (accumulator fully charged) and a lowest pressure (accumulator discharged). The accumulator shells must be constructed for the maximum pressure.

Hitherto in such plants, especially in those with steam boilers for very high pressures, the steam accumulators were inserted in the low pressure net, the opinion existing that for constructive, thermal and financial reasons it was of advantage to substitute to the greatest extent the boiler water spaces by heat accumulators in the low pressure net. As the storage capacity of 1 cbm water decreases with increasing pressure one assumed that the plant cost for the same storage capacity was far more favourable in the low pressure range than in the high pressure range.

The aim to avoid water spaces in the high pressure net was carried through more and more and led for example to certain boiler constructions, like the Sulzer one tube boiler and the Benson boiler, operating without any water space whatever. Plants with such boilers are as a rule provided with accumulators in the low pressure net. The maximum pressure of steam accumulator plants installed in power stations has hitherto not exceeded 16 atm. In one special case a pressure of 24 atm. was exceptionally provided. The best known of these plants is the accumulator plant at the power station Charlottenburg with a maximum pressure of 13 atm. The most modern Ruths accumulator plant at the Power Station Amsterdam has a maximum pressure of 15 atm.

The present invention applies to a new method differing entirely from the development hitherto. According to the invention accumulators are no longer to be provided in steam power plants for low pressure, but for a maximum pressure of more than 60 atm.

Hitherto it was assumed that the efficiency of the accumulator plant decreases with increasing maximum pressure. According to the invention, however, the efficiency increases with maximum pressures of more than 60 atm, as shown in Fig. 1.

In this diagram the costs of high pressure and low pressure accumulator plants are compared. In both cases the same capacity and extent of delivery is assumed.

On the abscisse the high pressures are entered and on the ordinate the purchase costs of the accumulator plant. As the prices vary according to the market and as the absolute values are of no importance here, but moreover, the relation of the prices to each other, only relative values are entered.

Curves K_{15}, K_{30} and K_{40} represent the price of the accumulator plant with a lowest discharge pressure of 15, 30 or 40 atm. The price of the low pressure accumulator normally used hitherto and working between 15 and about 2 atm. is marked with K_N; the curves show that the purchase costs of high pressure accumulators decrease with increase of maximum pressure.

The lowest entrance pressure of turbines of older type still in operation today is about 15 atm. If the high pressure accumulator plant is discharged to this entrance pressure of 15 atm., then the advantage of the high pressure accumulator over the low pressure accumulator begins at a maximum pressure of 60 atm.

An increase in pressure beyond 200 atm. is of no advantage. In fact the price curve K_{40}, i. e. for a lowest discharging pressure of 40 atm., climbs again. An accumulator fully charged up to a maximum pressure of more than 200 atm. can only be discharged to 30 atm. as for reasons explained later its water contents are entirely evaporated at such a pressure.

At discharge pressures of about 20 atm. upwards the lowest plant costs lie between maximum pressures of 100 and 200 atm.

The reasons for the surprising result that in power stations high pressure accumulators of more than 60 atm are more economical than low pressure accumulators are to be found above all in the fact that in cases of storage in such high pressure ranges the shells themselves take up a considerable part of the heat to be stored, giving it up again during the discharge period. The iron heat stored in the accumulator walls considerably increases the storage capacity.

Fig. 2 explains these conditions. Curves *a* and *b* represent the average storage capacity per cbm accumulator contents in a plant to be discharged at a pressure of about 30 atm., curce *a* representing the steam amount taken from the accumulator plant without considering the iron heat, curve *b* showing the capacity of the accumulator plant including iron heat. The course of curve *a* shows that the increase in capacity per atm. becomes less with increasing maximum pressure, and that in the upper pressure range an increase of the maximum pressure hardly enlarges the capacity.

The course of the capacity differs entirely if the iron heat is taken into consideration. Due to the iron heat the storage capacity of the accumulator increases with rising maximum pressure.

In addition to the iron heat the improvement of the specific steam consumption of the prime mover is a further reason for the economic superiority of the high pressure accumulator over the low pressure accumulator. The average steam consumption of the low pressure accumulator plant at Charlottenburg Power Station amounts to 8.67 kg/kwh. In a power plant with high pressure accumulator the steam taken from the accumulator is throttled to entrance pressure of the turbine and superheated. The steam consumption is thus improved considerably and amounts to about 4.8 kg/kwh. This is also one of the important reasons why the accumulator plant in the high pressure range has a considerably higher kwh capacity than in the low pressure range.

As in high pressure accumulators the accumulator steam is throttled to the entrance pressure of the turbine and the pressure thus remains constant, the accumulator turbine can operate at full load during the entire discharge period. In the case of low pressure accumulators the specific volume of the accumulator steam increases with increasing discharge, so that the output of the accumulator turbine decreases during discharge period and at the end of the discharging period amounts only to a fraction of the full load.

Considerable economic advantages are obtained by applying that invention to accumulator plants which store heat generated by electric current.

These plants had a comparatively low efficiency of about 15–18%, the accumulator having to be charged with about 6–7 kwh in order to obtain one kwh of stored energy. The storage of electric energy by means of high pressure accumulators with maximum pressures of more than 60 atm. according to the present invention enables an improvement in efficiency to more than 25%, i. e. for 1 kwh power to be supplied by the accumulator plant a charging of about only 4 kwh is necessary.

The heating of the accumulator water to the high temperatures required is best effected in a heater, which can, for instance, be constructed in such a way that the heat elements are arranged round a tube through which the accumulator water flows.

The efficiency can be improved still further if back-pressure steam or bleed steam is taken from the prime mover and supplied to a heat consumer, e. g. a hot water heating plant. It is also of advantage to preheat the water to be fed into the accumulator plant by means of bleed steam of the prime mover.

The heat generated by means of electric current can also be transferred to the accumulator water by means of a liquid with high boiling point, the heater need then not be constructed for high pressures.

Figs. 3–7 show examples of the invention. According to Fig. 3 the accumulator plant is charged by means of superheated, non-condensing low pressure steam, according to Fig. 4 by means of high pressure steam, and according to Figs. 5–7 by means of electric current. In the plant according to Fig. 3 a steam generating plant consisting of boilers **1** supplies steam to turbine **2**. Preheater **4** is formed as a mantle surrounding part of main steam line **3**. **5** represents the high pressure accumulator. Line **6**, in which pump **7** and regulating valve **8** are inserted, leads to preheater **4**. Water from the accumulator passes through this line into the preheater. The steam thus generated passes through line **9** into the accumulator. Steam is taken from the accumulator by means of reducing valve **10**. The accumulator steam is superheated by superheater **11** and flows through line **12** into main steam line **3**, where the accumulator steam mixes with the boiler steam and passes into turbine **2**.

Naturally it is also possible to operate turbine **2** with accumulator steam only, for example during the time when boiler **1** is started.

Accumulator valve **8** can be governed depending on the steam temperature before turbine **2**, or depending on the steam pressure in the main steam line.

The pressure of the boiler plant can, for example, amount to 30 atm. and the superheating temperature to 450°. The maximum pressure of the accumulator plant can, for example, amount to 160 atm., a pressure range of 160–30 atm. being used for the storage process. The steam taken from accumulator **5** must be substituted after completion of discharge by pumping water, e. g. condensate from tank **13**, into the accumulator.

In the example according to Fig. 4 the plant contains high pressure boilers **21** of 120 atm. and low pressure boilers **22** of 15 atm. Back pressure turbine **23** is inserted between the two nets. Condensating turbine **24** is connected to the low pressure net. The accumulator plant consists of 3 containers **25**, **26**, **27** connected in series. Automatic valves are inserted in the connecting lines. **28** is the charging valve and **29** the discharging valve. Superheater **30** is arranged in accumulator **25**. The maximum pressure of the accumulator plant amounts to 120 atm. Contrary to the example shown by Fig. 3 the accumulator plant is charged directly by means of high pressure steam. Charging valve **28** can be governed from high pressure net and discharging valve **29** from low pressure net.

In Fig. 5 the high pressure accumulator is marked **31**, the steam turbine **32**. The accumulator water is heated in the heater by means of electric current. Owing to its different temperature the water circulates through lines **34** and **35**. The water taken from the accumulator in form of steam can be substituted either by pumping a corresponding quantity of water as a whole into the accumulator after completion of the discharging period, or by supplying water to the accumulator during charging period. In this case a non-return valve can be provided in pipe line **34** and the water supply can be regulated by means of valve **37**.

Fig. 6 represents a plant, in which the turbine steam is used for hot water generation. There are two accumulator tanks **41** and **42**. The charging system of the accumulator plant consists of lines **43**, **44**, pump **45**, regulating valve **46**, heater **47** and line **48**. Accumulator **42** is charged by steam supplied from accumulator **41**. Steam discharge is effected by means of reducing valve **49** and superheater **50**. The steam flows from here into turbines **51**. Surface preheater **52** and mixing preheater **53** are connected to the turbines. The hot water is pumped by pump **54** into flow-forward line **55**. **56** is the flow-back line. Accumulator **57** is inserted between flow-forward and flow-back lines. The water to be heated is discharged by means of pump **58**, and can be regulated by the temperature of the heated water behind preheater **53**. Line **59** leads from forward-flow line **55** into the charging system. Water is led into the accumulator plant by means of this line. Throttling valves **60** and **61** are alternately opened or closed.

In Fig. 7 the accumulator plant **71**, **72** is laid out similar to Fig. 6. For the charging of the accumulator plant a liquid with high boiling point is used, circulating by means of pump **73** between heater **74** and accumulator **71**. Equalising tank **75** is connected to the back-flow. Charging can be regulated by means of valve **76**.

Liquids with high boiling point can also be used for superheating the accumulator steam. For this purpose a heat exchanger can be provided in line **77**. It is also of advantage, especially if the accumulator steam is to be superheated by means of liquid, to store the liquid with high boiling point in a separate tank. The accumulator can be connected to line **77** at the same time substituting equalizing tank **75**.

The plant can be simplified further by using the preheater heating the accumulator water during charging for the superheating of the accumulator steam during discharging.

In addition to the examples described in the foregoing, further arrangements are possible.

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