Modeling Turbine By-Pass Operation

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ABSTRACT

Turbine by-pass systems can substantialy improve the behaviour of base load power plants submitted to cyclic operation or frequent load rejections.This technical solution ensures a better matching of the boiler steam and the turbine metal temperatures during start-up or re-start. A 100% capacity by-pass system can also provide a quick re-start capability after short load rejections.

The use of the by-pass systems usualy brings fuel and condensate savings,reduce solid particle errosion but they also require a more sophisticated control system and careful tuning of the plant components.

A detailed study is therefore required in order to determine the design conditions for a by-pass system (including controls) both for a new power plant and for an existing one.

Our model is based on a medium size (550 Mw generator output) reheat fossil power plant.The PEPSE general cycle model includes some 110 elements and 250 streams.Specific operations,schedules and controls are included for each of the cases presented henceforth.Most of them occur under usual,steady-state operating conditions but there are a few ones representing only test cases.In all the models, a "minimum change" approach towards the general cycle model has been adopted.

The attempt to use the general model for all the cases,with specific changes, has failed.Severe divergence problems and detection of their source led us finaly to the conclusion that sepparate models of each case are much more appropriate.

INTRODUCTION

The turbine cycle heat and mass balance including active by-pass systems are not usual for power plant performance calculations.Several controls are simultaneously activated in order to ensure the vendor operating prescriptions such as:cold reheat steam maximum temperature; main condenser steam inlet enthalpy;turbine load;a.s.o.On the other hand some variables are allowed to change only along vendor supplied curves such as:pump efficiecy as function of inlet flow and pressure; throttling valve flow as function of inlet pressure;turbine stage parameters (bowl pressure,enthalpy,efficiency) as functions of steam flow; a.s.o.The modelling of the different by-pass operating cases is therefore quite complicated since the outcome of several different restrictions cannot be foreseen.

Our purpose was to determine a modelling strategy which will allow for as many cases as possible to be solved with the same basic configuration of PEPSE elements.The examples presented illustrate both the difficulty and some of the possible solutions of the problem.

In order to get a more realistic power plant model we preferred the vendor provided scheduled data to the constant estimates.It should be noted that the modelled turbine has been used by the vendor in a power plant provided with a high and an intermediate pressure by-pass systems.

1. TURBINE BY-PASS SYSTEM PURPOSE AND DESCRIPTION

The turbine by-pass system enables the plant operator to achieve several important objectives such as:

-matching the temperatures of the entering steam and the turbine metal during start-up (or re-start) especialy for power plants in cycling operation;

-providing a quick re-start after load rejection by keeping the boiler fully loaded;

-providing a fast valving capability through partial load rejection.

It might be concluded that the by-pass system gives additional flexibility to base-load designed power plants.

For a turbine cycle with reheat,two by-pass systems have to be provided,for the high and intermediate (including low) pressure groups respectively.

A rather complex control system has to be developped for such a power plant.Without presenting it in full detail,we have to remind some of its features which are mandatory for the model.One control branch keeps the cold reheat temperature at a certain value,using spray from the boiler feed pump outlet.A second control branch keeps the main condenser steam inlet at a certain temperature (or enthalpy).A spray from the condensate pump outlet is used for this purpose.The high pressure turbine throttling valve is load controled when the plant is keeping the boiler at full load (constant pressure operation).For the high pressure by-pass the valve opening is controled by the pressure in the main steam line.

For the intermediate pressure by-pass,the control system has to activate both the by-pass and the throttling valve according to the pressure in the hot reheat line and the turbine load [1],[2].

2. TURBINE CYCLE FULL MODEL DESCRIPTION

The turbine cycle full model is presented in fig.2-1.The boiler is not modelled in detail,a pair of INPUT/OUTPUT elements is used instead (no.1 and 50).For the turbine,elements of type 08 (general turbine stage) are used (no.5,6,7,8,9,10,11,12 and 13).Vendor supplied schedules are used to link the extraction pressures,enthalpies and efficiencies to the steam flow.For the boiler feed and condensate pumps (no.25,40 and 105) efficiency versus flow schedules are built in the model.

Although **TTD** and **DCA** versus turbine load schedules for all the heaters (no.19,20,22,23,27 and 28) were at our disposal,it must be emphasized that they are not adequate for by-pass cycle balances since the steam and water conditions are unusual.A full description of the heaters is needed for a **DESIGN** mode run.At this stage of the study we decided that an estimate of the **TTD**'s and **DCA**'s based on experience can still be satisfactory.No pressure drop has been taken into account.

The model includes the sealing system of the turbine and the air preheating heater (no.101).

The streams connecting the turbine to the heaters (steam extractions no.173,125,132,134,147,148 and 149) have a constant percentage pressure drop.

The reheater (no.32) pressure drop is given as a constant percentage of the cold reheat pressure.

Some valves (no.46,52,108 and 109 for example) have been introduced only for computational purposses ,they do not appear in the real plant.

The model has 113 elements,155 streams,3 or 4 controls,30 or 35 schedules,10 to 15 operations.

For a standard 100% boiler and turbine load cycle, with **PEPSE** provided default convergence data the balance is solved within 68 iterations.

Note.

These valves have to ensure a 0.0 flow in the downstream lines.A 0.0 extraction flow does not neccessarily produce a 0.0 outlet drain flow at the respective heater although no drain inlet is present (see heaters no.23,28).

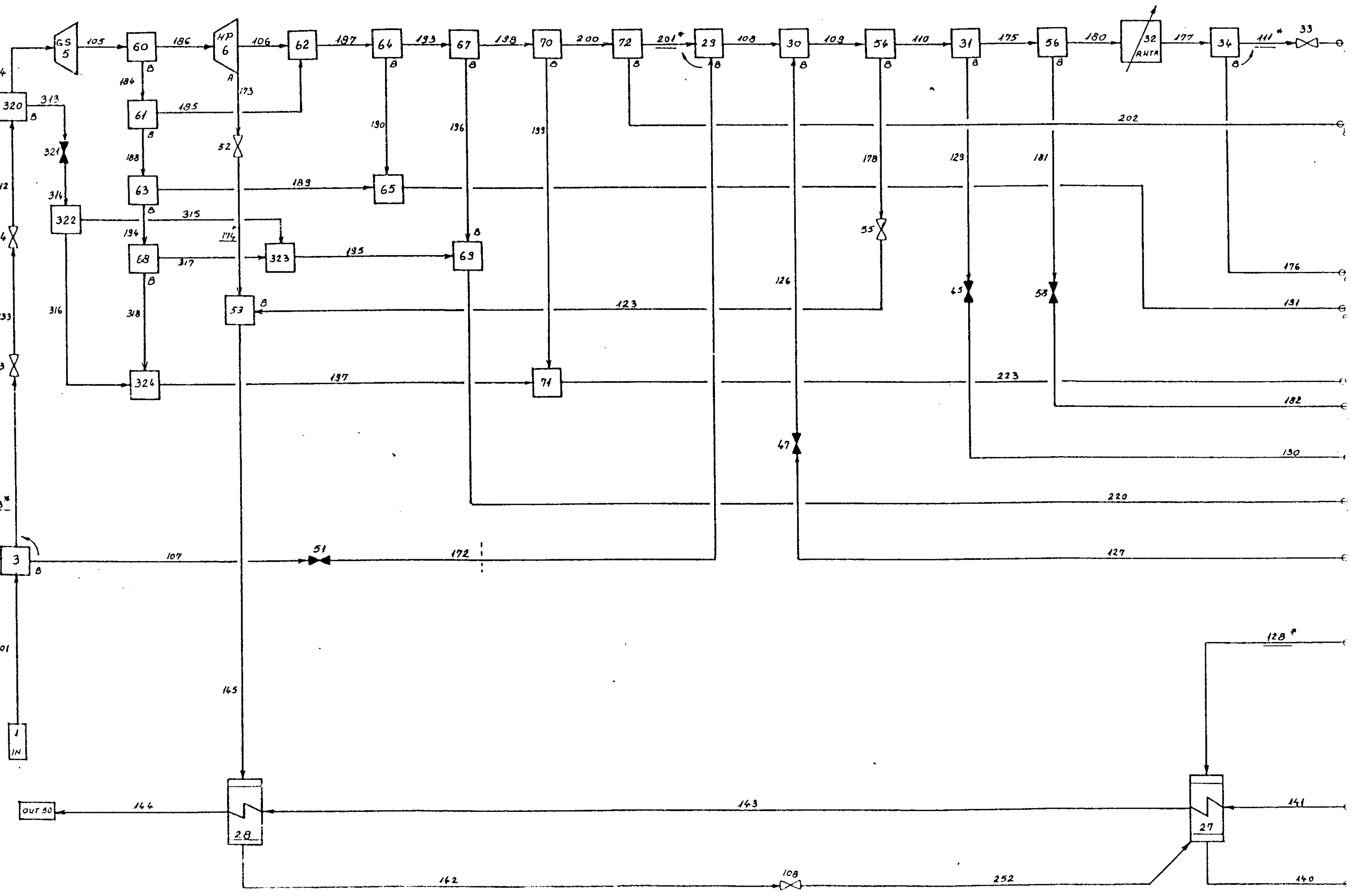

FIG. 2.1: FULL MODEL OF TURBINE CYCLE

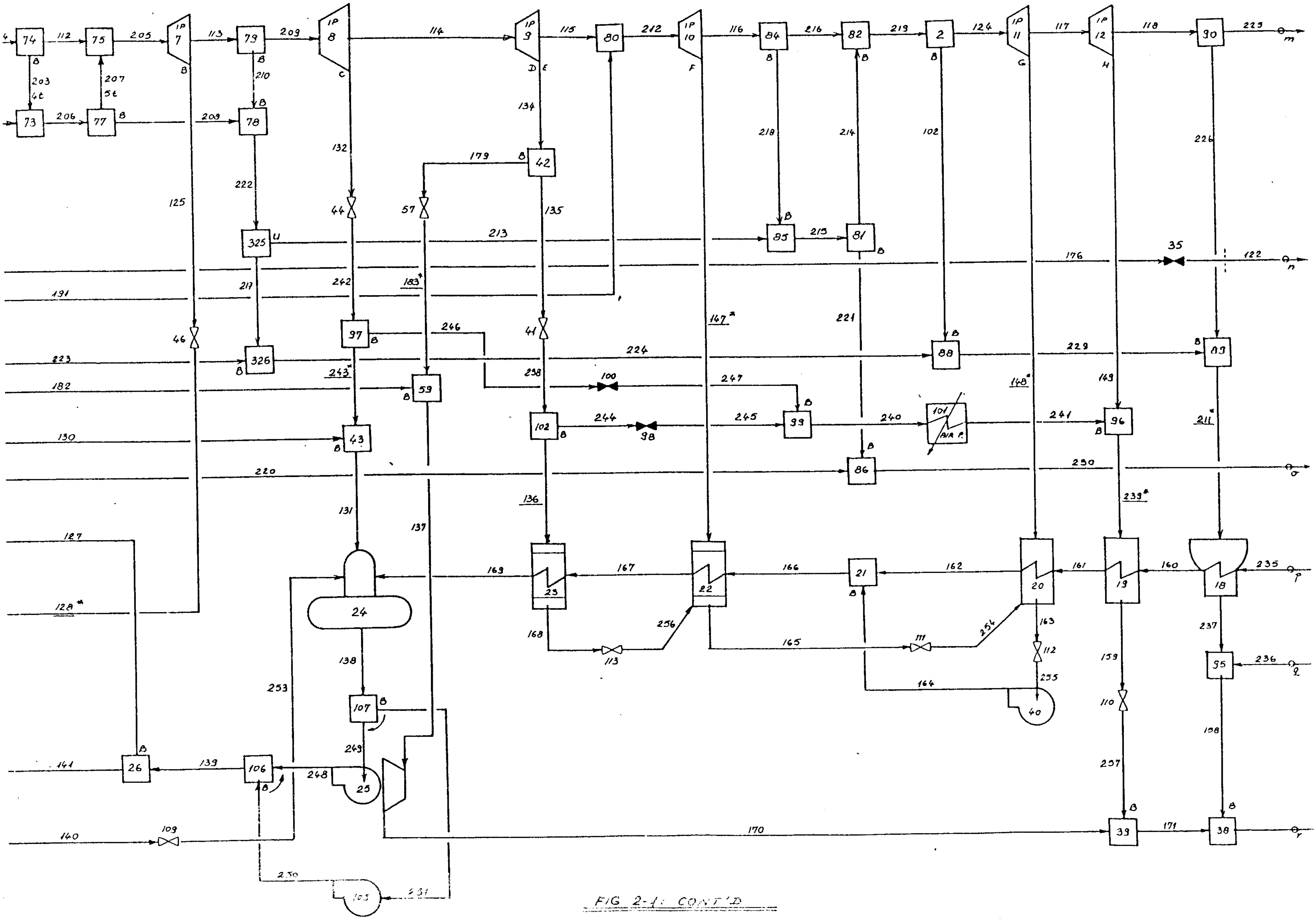

FIG 2-1: CONT'D

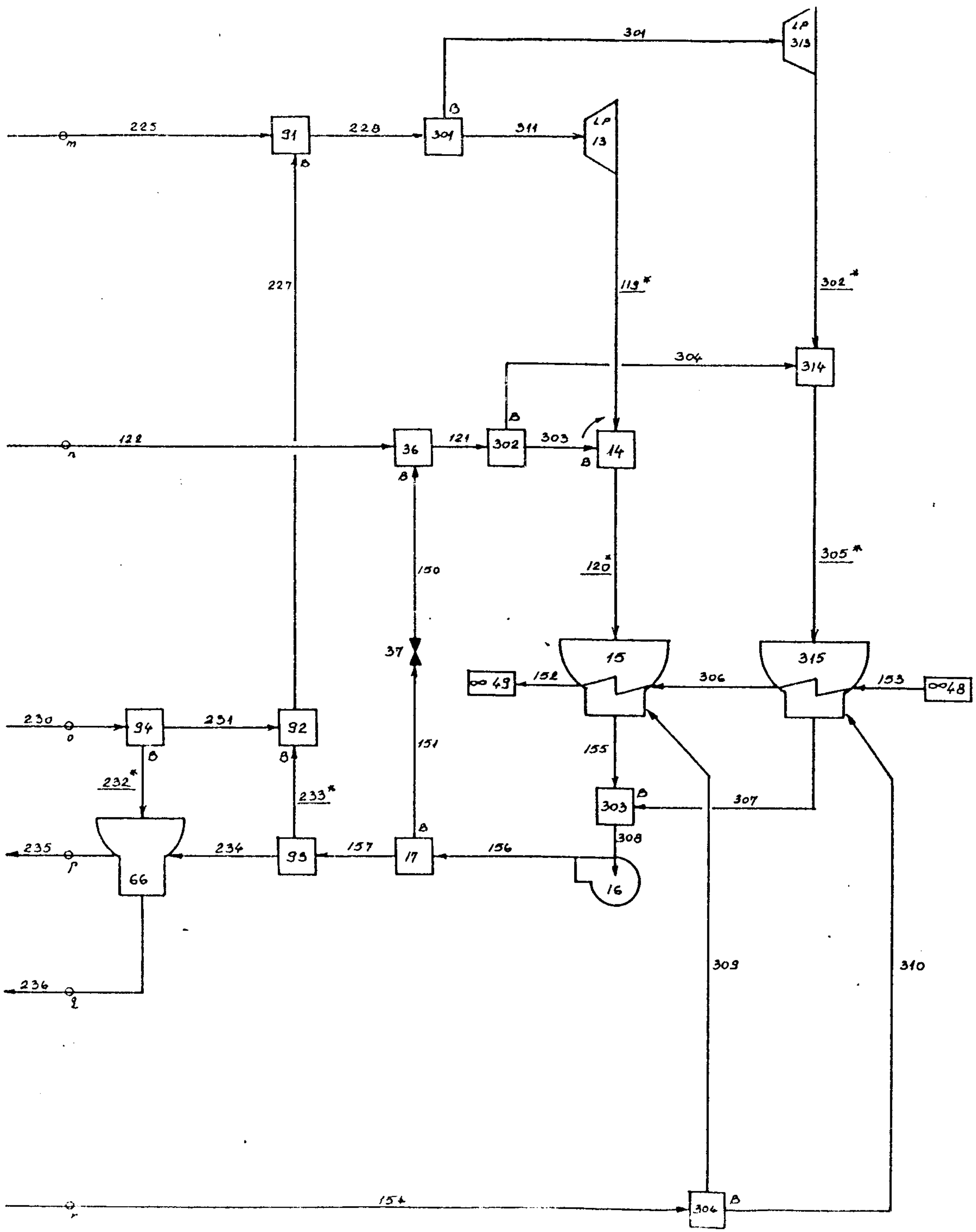

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FIG. 2-1: CONT'D

3. TOTAL TURBINE LOAD REJECTION WITH FULL BOILER LOAD

Several modelling attempts were made until a converged solution has been obtained.

The first attempt was to shut only the two valves situated at the high and intermediate pressure turbines inlets (no.33 and 103).This attempt was not successful because flows greater than 0.0 did still appear in the extraction streams.Even after we closed them and the heater drain lines too no solution could be obtained (see fig.3-1.).It appears that the solving order established by PEPSE for a normal turbine cycle model - with active turbine elements - is not suitable for a total by-pass calculation.

The seccond attempt has been to define two envelopes (see fig.3-2.) One envelope (no.1) included the active elements and the other (no.2) the inactive ones (turbine elements).In order to define the boundaries of the two envelopes,streams of the type 6 were used (marked with * in fig.3-2. such as 103,174,201 arround the high pressure turbine).PEPSE solved first envelope no.1 and then no.2 and obtained a converged solution within 172 iterations.

Another attempt consisted in a different approach:all the inactive elements (i.e. the turbine elements,their connecting streams,the low pressure heaters,a.s.o.) were eliminated from the overall model (see fig.3-3.) and only the elements actively involved in the by-pass operation retained in the model.The new model has only one pair of INPUT/OUTPUT elements (no.1 and 50) and one pair of SINK/SOURCE elements (no.48 and 49).This model is the simplest to be used for this case. However,this configuration could not be solved.The program did not identify the cause and the "abnormal" terminations gave irrelevant warning messages (such as:maximum number of iterations attained;energy or mass balance not attained;thermodynamic parameters erroneous;a.s.o.).

After a considerable amount of time and effort the real cause has been identyfied:the model is of the "closed flow circuit" type!

The alternative using type 6 streams for the lines no.138 and no.169 could not be solved either.After several trials a new configuration has been devised (see fig.3-4.).These lines were "cut" and two pairs of **SOURCE/SINK** elements were introduced (no.219/222 and no.227/226).Some special operations were added in order to have for each pair the same parameters (pressure,temperature, entropy,flow) on both sides.This last configuration has been solved within 49 iterations.

It should be noted that the maximum and minimum flows given for the splitters have an important influence on the number of iterations needed and sometimes even on the possibility to reach a solution at all.

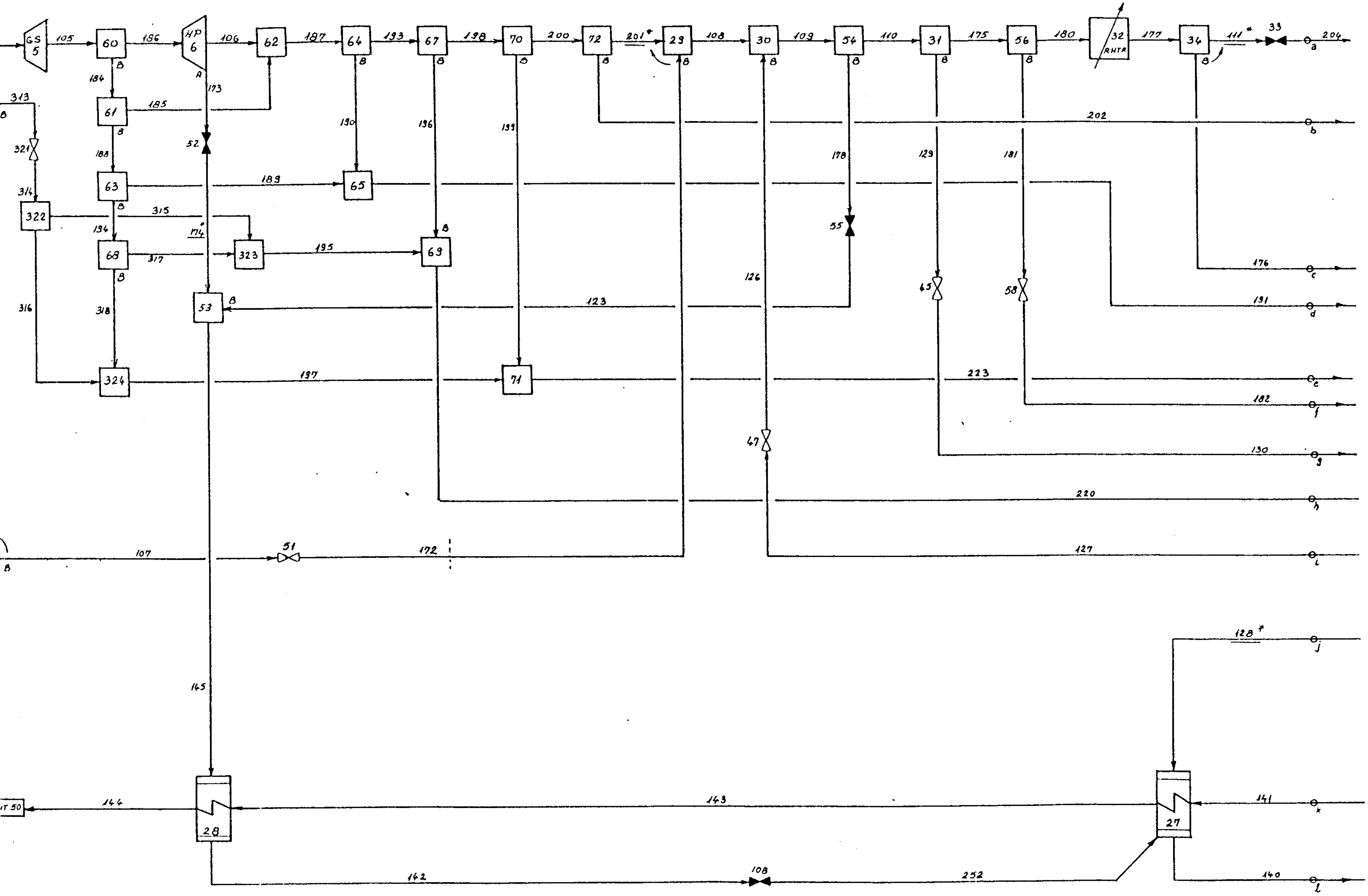


FIG. 3-1: FULL MODEL WITH TOTAL LOAD REJECTION

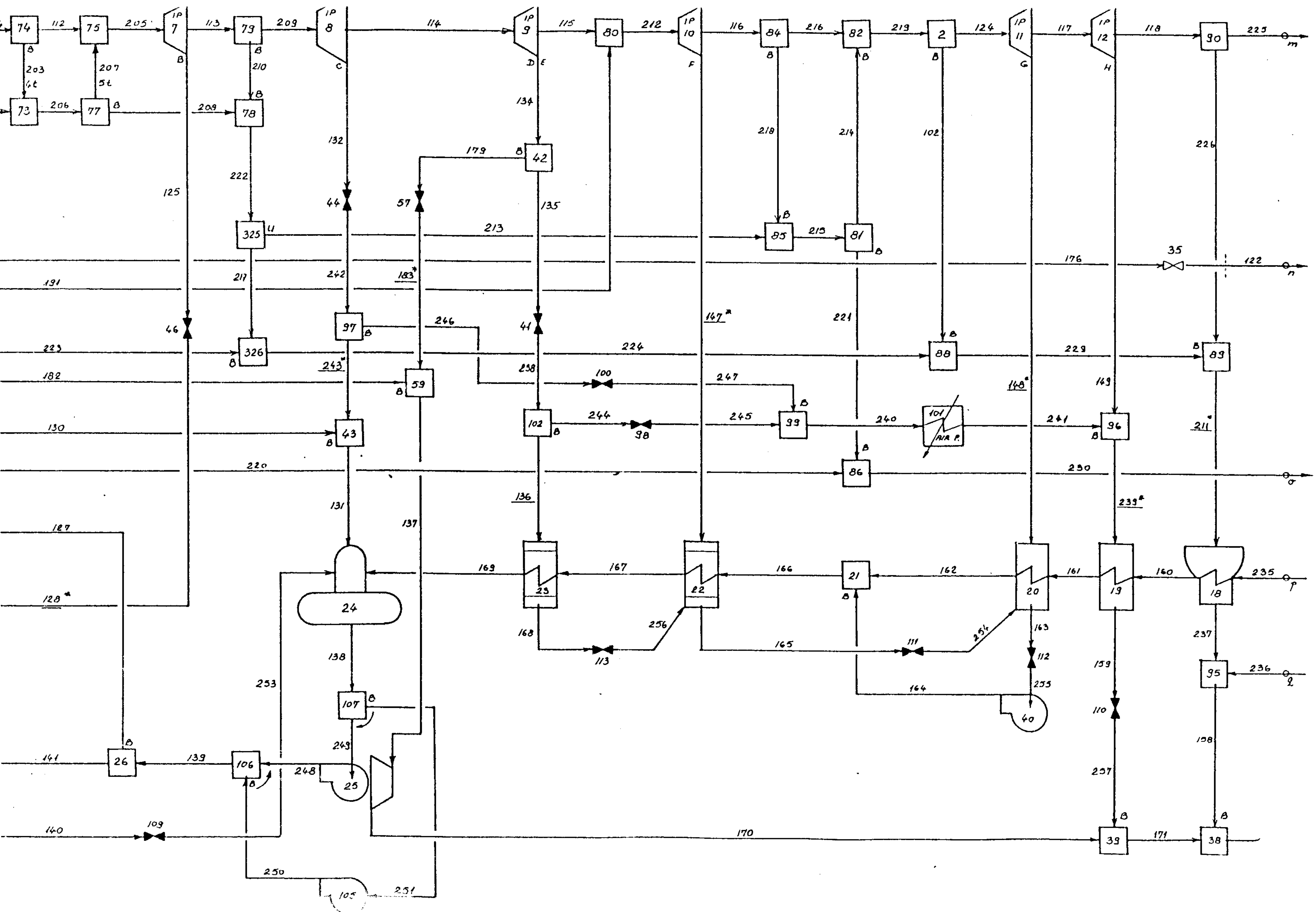
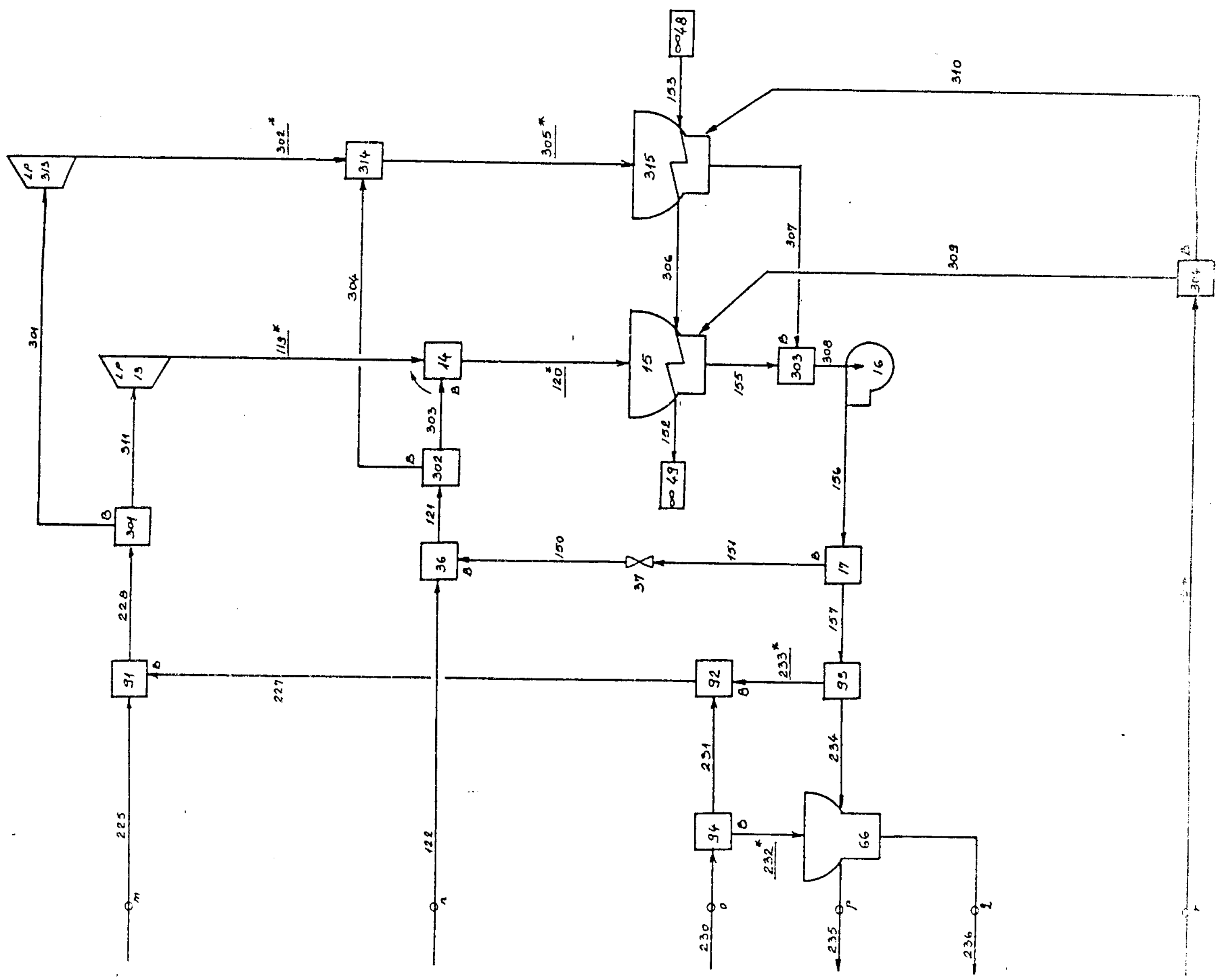


FIG. 3-1: CONT'D



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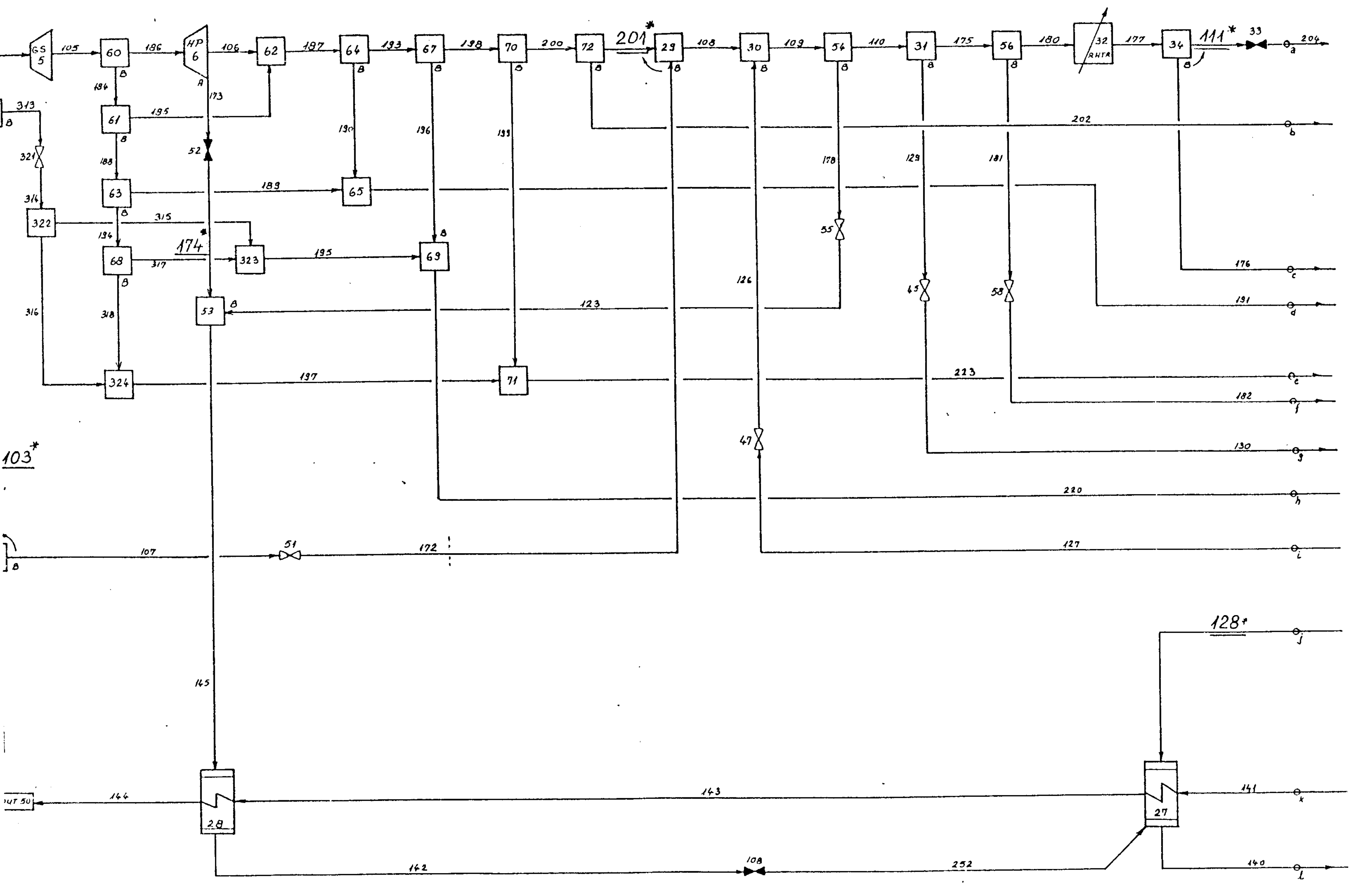

FIG. 3-2: FULL MODEL WITH ENVELOPES

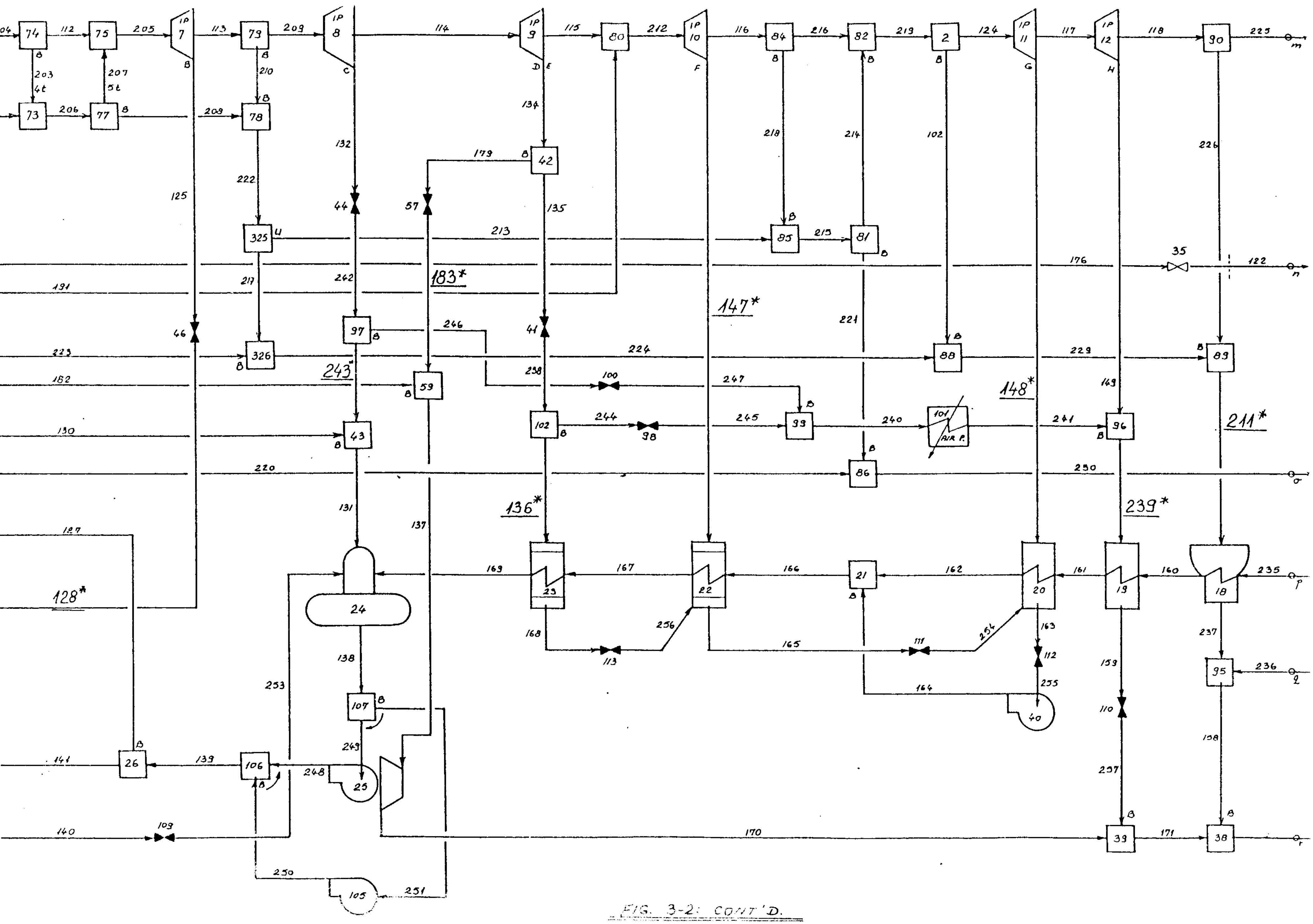

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FIG. 3-2: CONT'D.

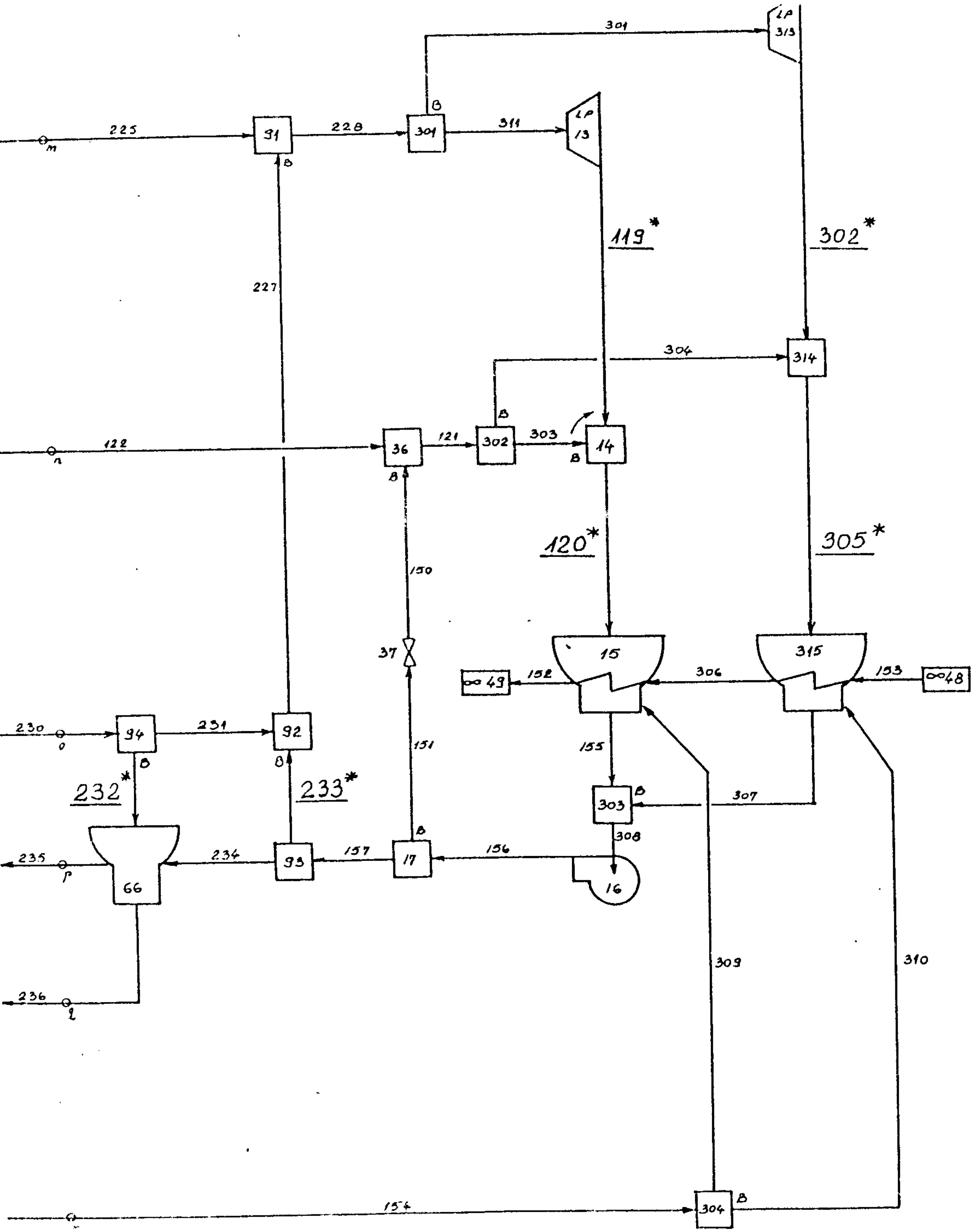

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FIG. 3-2 : CONT'D.

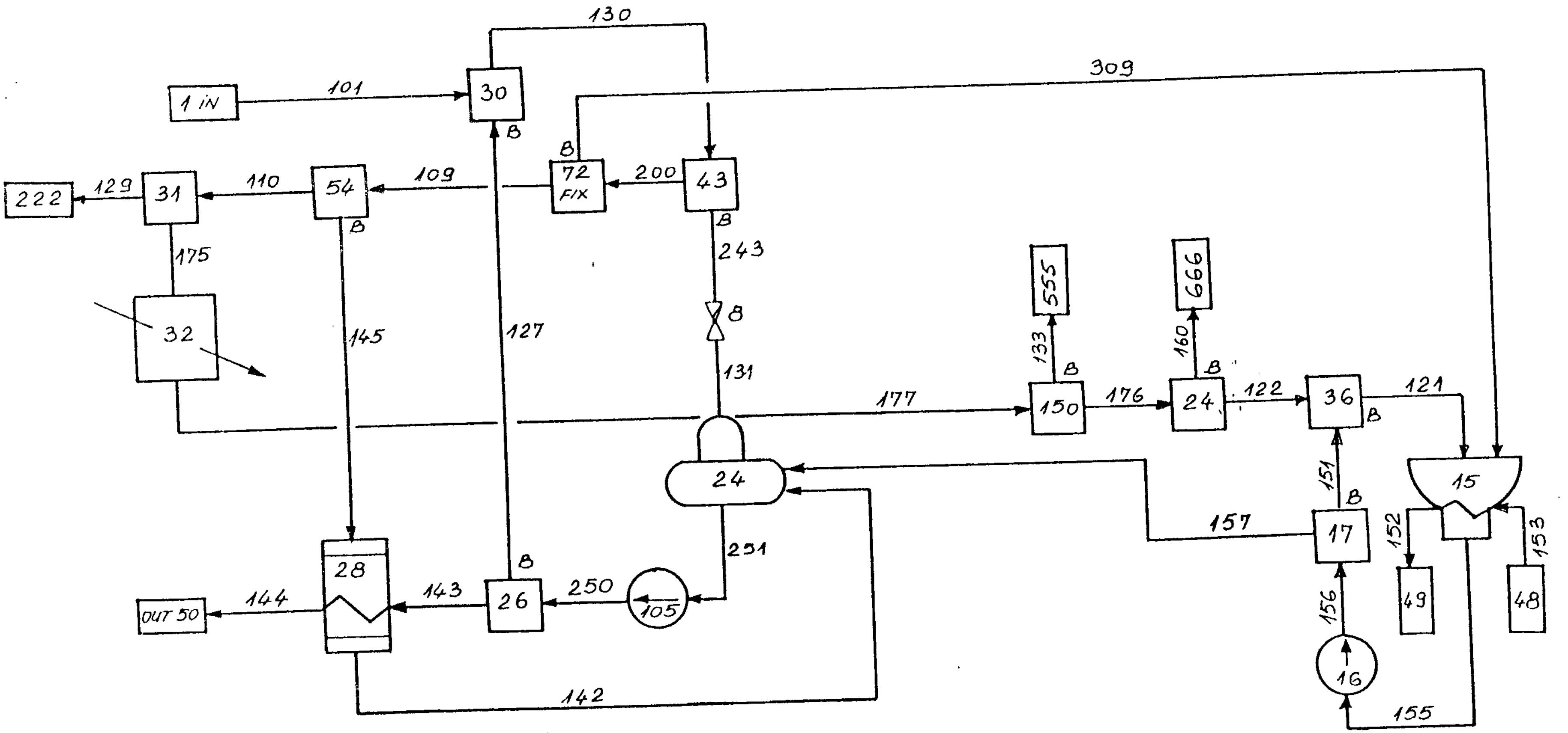

FIG. 3-3 : SIMPLE MODEL FOR TOTAL TURBINE BY-PASS.

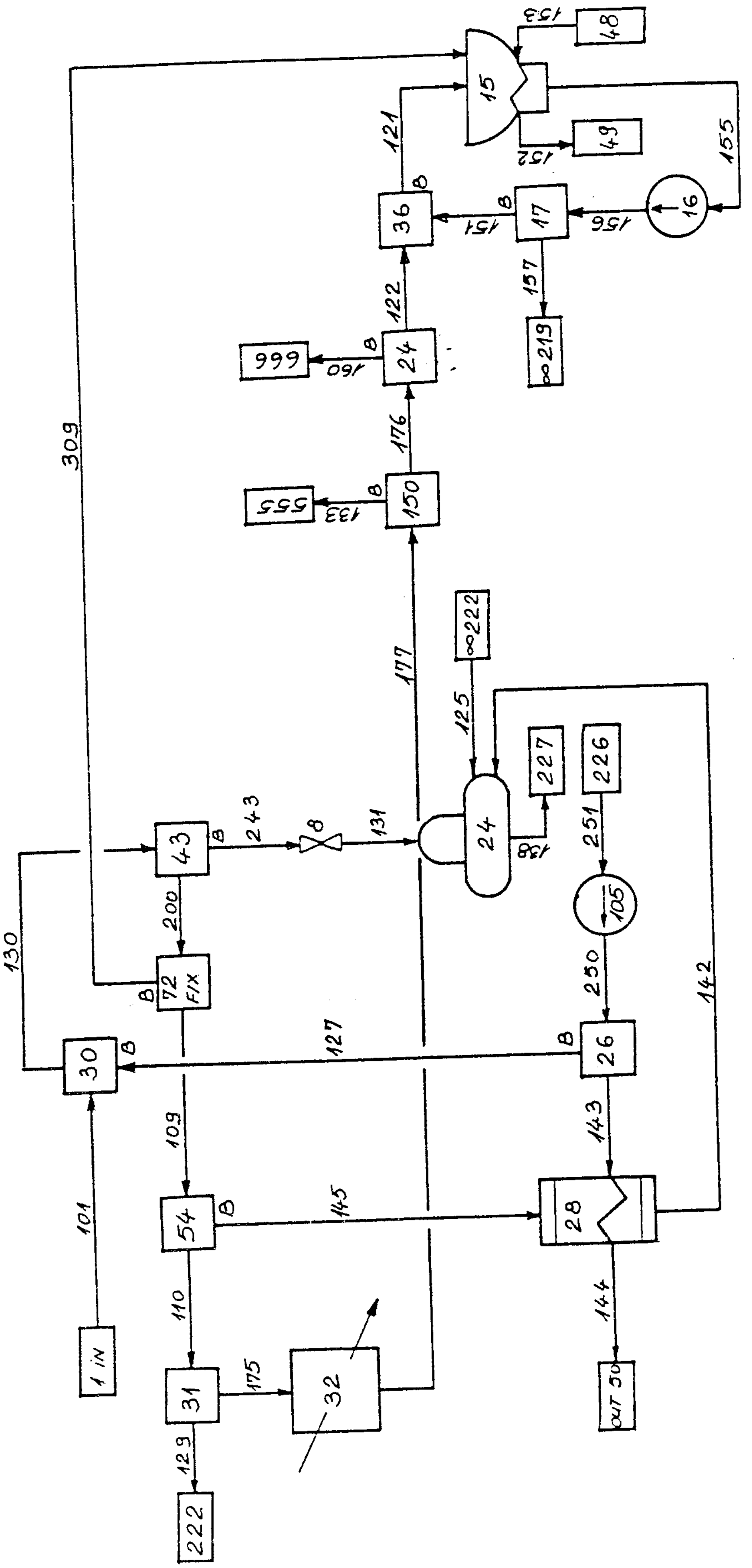

FIG. 3-4: SIMPLE MODEL - MODIFIED

4. PARTIAL TURBINE LOAD USING THE BY-PASS SYSTEM

At power plant start-up or at partial load rejection the turbine cycle is characterized by a higher boiler load than the turbine [2].

Two main alternates have been tried:

a. The full model (see fig.2-1.) has been provided with a supplementary set of operations and controls in order to obtain the specified boiler and turbine loads.The high and intermediate pressure (including low) turbine power outputs were separately controled.

b. Option 3 (generator output specified) has been used in conjunction with a special operation in order to obtain the given load and in the mean time keep the boiler steam production at a given value.The use of the **INLET** element alone would have caused the automatic reduction of boiler load.Therefore,the full model has been altered and a supplementary **SOURCE** type element used to supply steam to the high pressure by-pass line.

Alternate a.

The boiler was kept at 100% load and the turbine at 70% load.The high pressure heater (no.28) and the deaerator (no.24) were fed with steam from the cold reheat.The electrical driven feed water pump (no.105) was activated (see fig.4-1.).The precision for the controled values has been reduced to 10%. A converged solution has been obtained within 22 iterations.

The same result (convergence and small number of iterations) has been obtained for the model in fig.4-2.The high pressure by-pass line has been provided with a sepparate **SOURCE** element (no.333).Under the same operating conditions,the deaerator (no.24) and the boiler feed pump turbine (no.25) were supplied with steam from the intermediate presssure turbine (see fig.4-2.).

For a 100% boiler load and 30% turbine load,the model in fig.4-1. could not be solved,when all the elements were included in one envelope. As we could see from the "solving order" array, the solution path adopted by the program was not appropriate (first the turbine elements and then the by-pass related lines and sprays).

We divided the model into two envelopes,as for the total by-pass but with the turbine elements in envelope 1.This approach led to a converged solution within 30 iterations.

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* NOTE

The solutions obtained for the normal and total by-pass operation were calculated with high convergence precision.This explains the relatively high number of iterations needed.The partial load by-pass calculations were conducted at a lower precision and thus a relatively lower number of iterations was needed.A special remark should be made regarding the cases where the high precision required led to divergence of the solution.This situation is probably due to a combination of steep function changes and the PEPSE calculation procedure (Newton).

** NOTE

Although not specificaly for the use of PEPSE,it should be noted though that the schedules for TTD's and DCA's of the heaters have to be abandoned for all the cases presented in this section.The exact answer is to use the DESIGN mode (if all the neccessary data are available). Otherwise,good engineering judgement or measurements should provide the values.

Alternate b.

The use of the special option 3 (the generator output is given) has not led to any convergent solution.Sometimes it even broke down in a "catastrophic" manner (log0.0 !).This is probably due to very strong "jumps" in the iterating process.

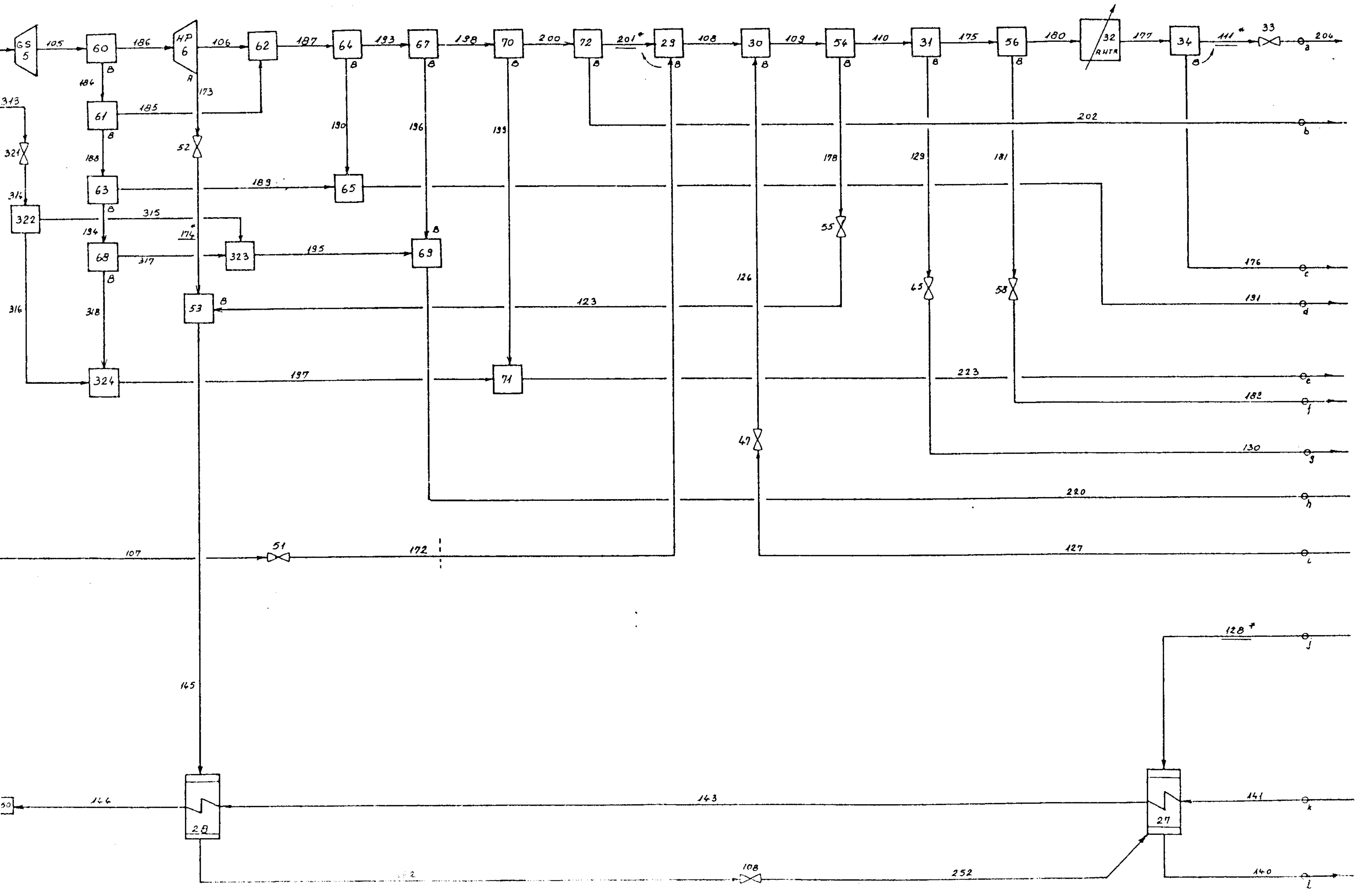

FIG 4-1: FULL MODEL FOR PARTIAL LOAD BY-PASS.

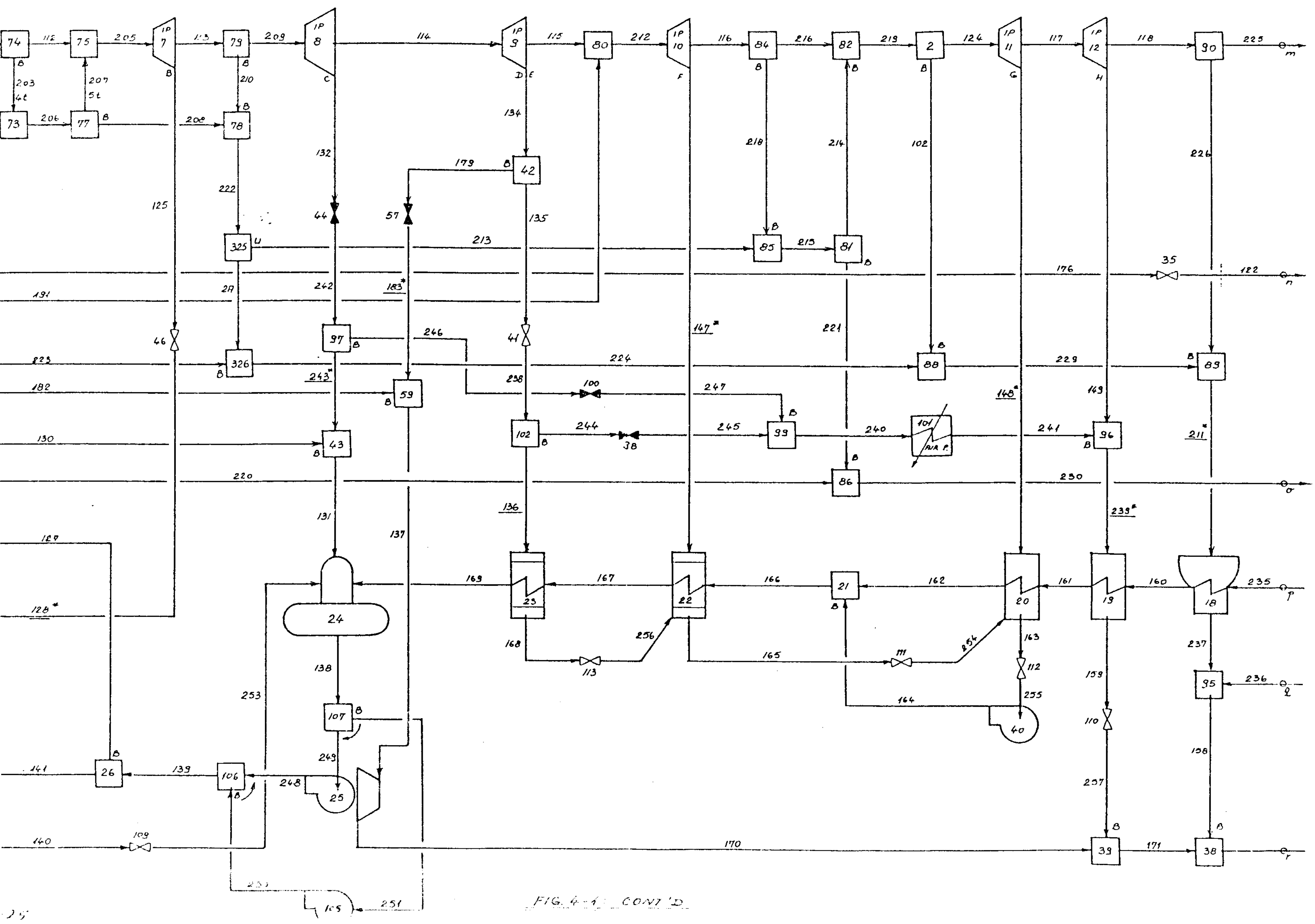

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FIG. 4-1 CONT'D

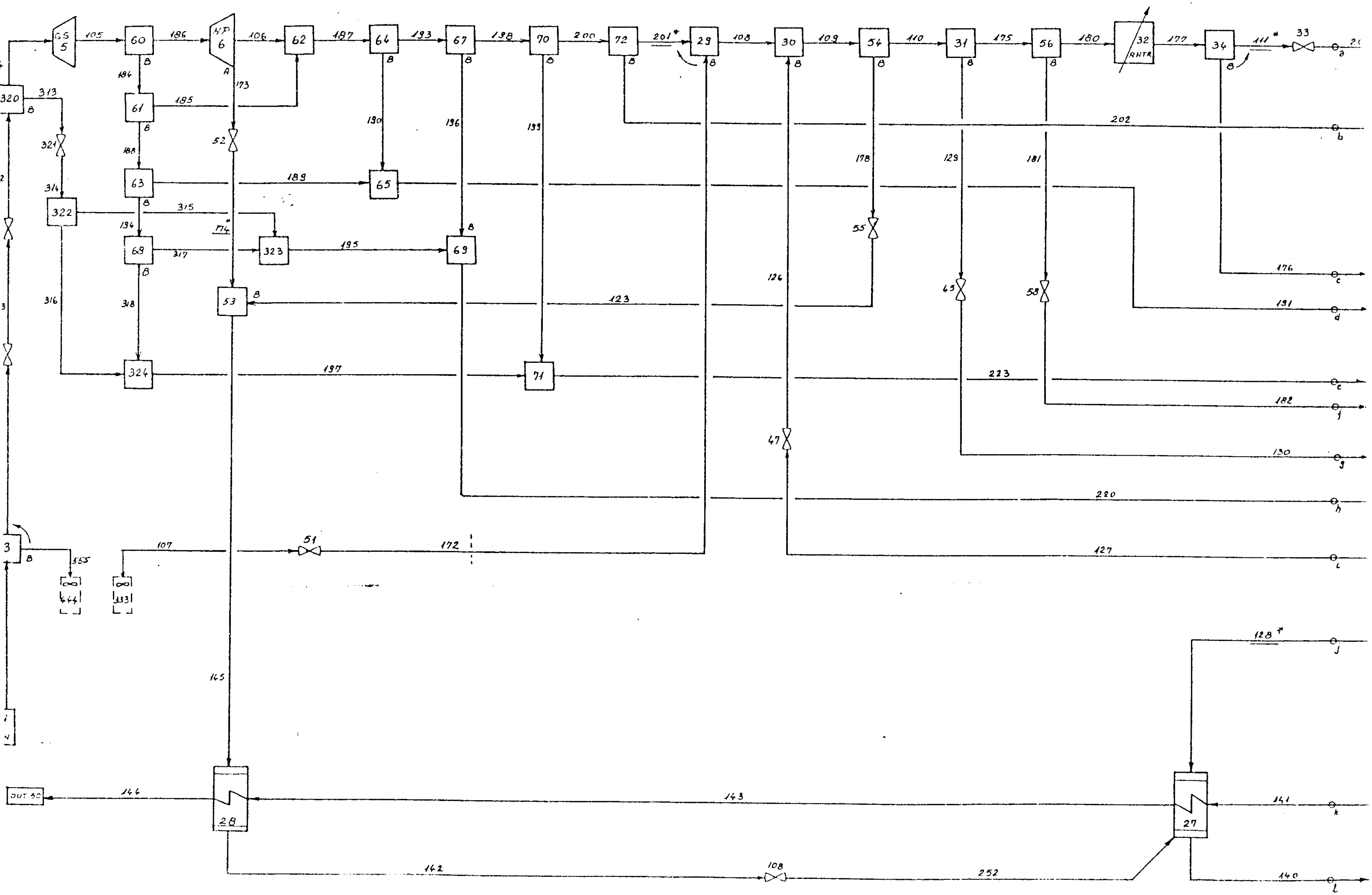

FIG. 4-2: FULL MODEL WITH PARTIAL TURBINE LOAD – DETAIL

5. CONCLUSIONS

At this stage of our experience with PEPSE, we might conclude that specific models have to be built for each turbine cycle operating condition. This approach seems to be less time consuming and the results more predictable than the use of a main model and its derivates.

Usualy, there are several modelling possibilities for each operating condition. Whatever should be the user's strategy in building the models -either from small solved blocks or from a modified main model- the final result (convergence) cannot be anticipated. The superposition of several constricting conditions (i.e. schedules, controls, built-in options, a.s.o.) can lead to unpredictable outputs.

It looks that for certain "classical" power plant configurations, some kind of solution "charts" (i.e. solving order) should be built for alternate models. These "charts" could help substantially the user in modelling special applications such as the by-pass operation.

6. REFERENCES

[1]. By-pass stations for better coordination between steam turbine and steam generator operation, P.Martin;L.Holly (M.A.N.),American Power Conference, April-1973.

[2]. Assessment of fossil steam by-pass systems, EPRI Research Project (CS-3717) no.1879-1, 1984.

[3]. PEPSE Manuals vol.1,2 and 3.,PEPSE Inc.