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(54) Title: STEAM TURBINE AND STEAM GENERATOR SYSTEM AND OPERATION THEREOF

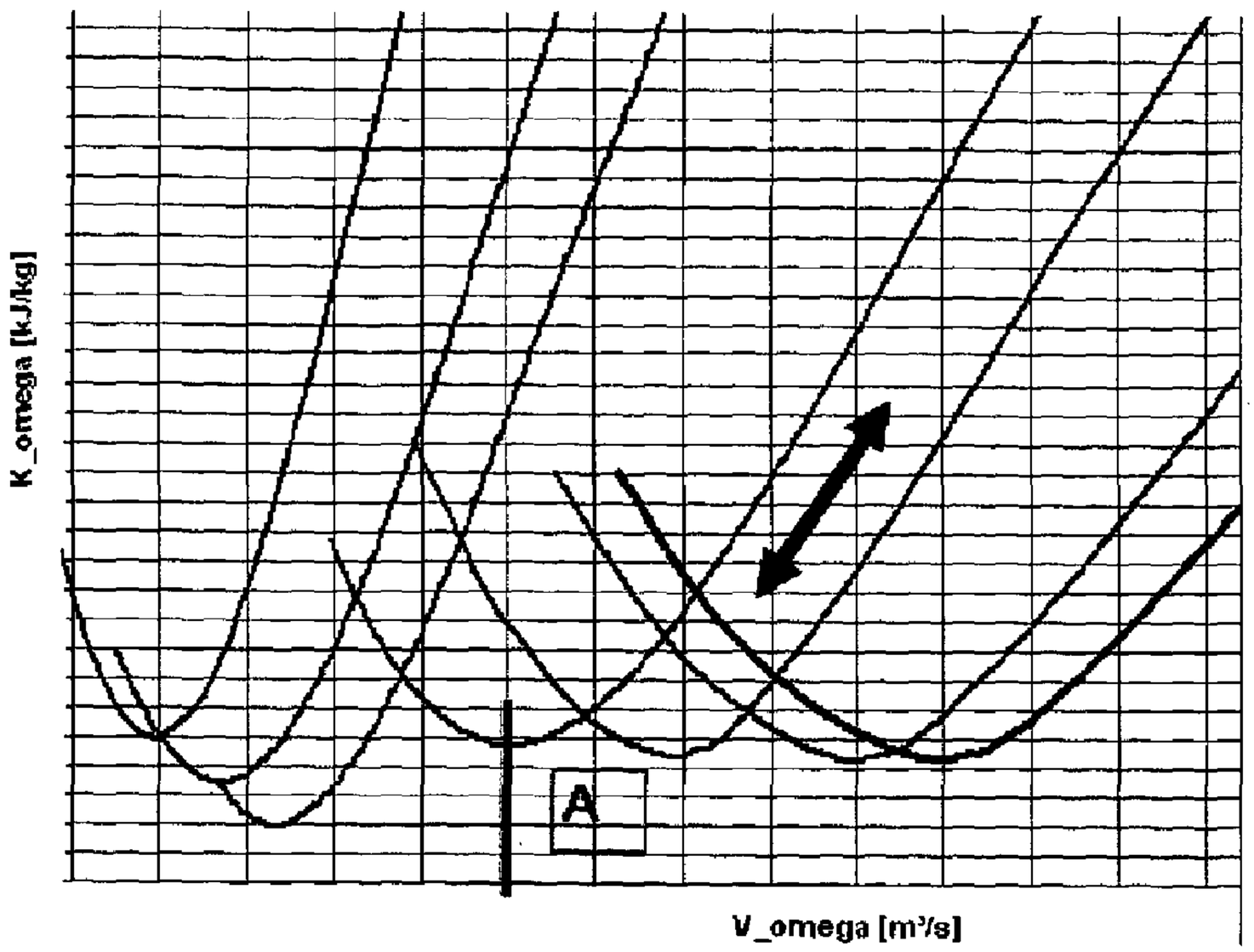

Figure 1

(57) Abrégé/Abstract:
A steam turbine system is described comprising fluidly in series: at least one high pressure turbine and/ or at least one intermediate pressure turbine and at least one low pressure turbine; and further comprising steam outlet means to enable extraction of auxiliary process steam from a location upstream of the low pressure turbine and for example between the intermediate pressure turbine and the low pressure turbine; and at least one flow restrictor in a steam extraction conduit from the or each low pressure turbine. The system is described as part of a steam generator fuelled by carbonaceous fuel combustion with post combustion carbon capture capability.

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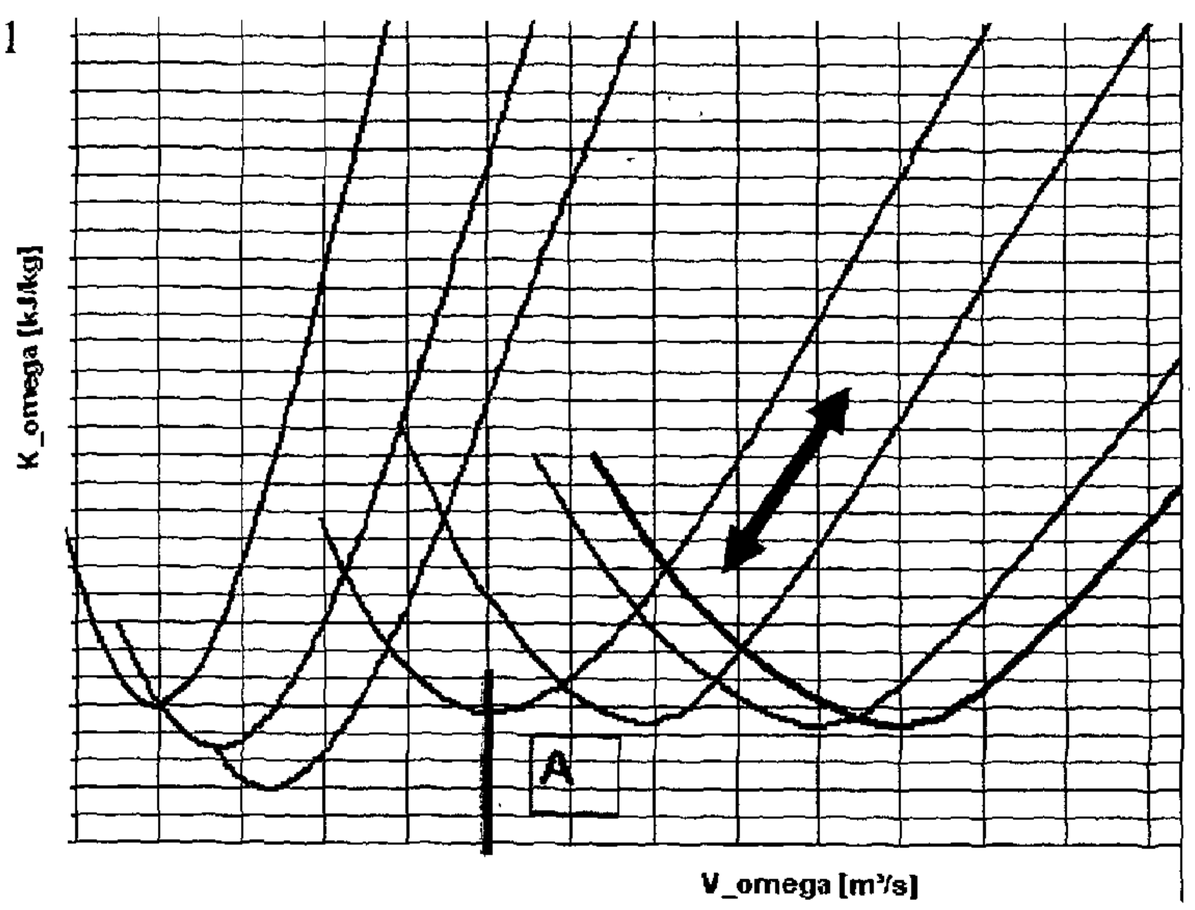
Figure 1



(57) Abstract: A steam turbine system is described comprising fluidly in series: at least one high pressure turbine and/ or at least one intermediate pressure turbine and at least one low pressure turbine; and further comprising steam outlet means to enable extraction of auxiliary process steam from a location upstream of the low pressure turbine and for example between the intermediate pressure turbine and the low pressure turbine; and at least one flow restrictor in a steam extraction conduit from the or each low pressure turbine. The system is described as part of a steam generator fuelled by carbonaceous fuel combustion with post combustion carbon capture capability.

WO 2012/001391 A3

STEAM TURBINE AND STEAM GENERATOR SYSTEM AND OPERATION THEREOF

The invention relates to a steam turbine system and a steam generator system and to the optimum operation thereof in particular together with a post combustion carbon capture plant.

Most of the energy used in the world today is derived from the combustion of fossil fuels, such as coal, oil, and natural gas. Post-combustion carbon capture (PCC) is a means of mitigating the effects of fossil fuel combustion emissions by capturing CO_2 from large sources of emission such as thermal power plants which use fossil fuel combustion as the power source. The CO_2 is not vented to atmosphere but is removed from flue gases by a suitable absorber and stored away from the atmosphere. Other industrial processes where similar principles might be applicable to capture post-process CO_2 might include removal of CO_2 generated in a process cycle, for example removal of CO_2 from the process flow during production of ammonia, removal of CO_2 from a natural gas supply etc.

It is known that CO_2 can be separated from a gas phase, for example being the flue gas of a thermal power plant, by means of absorption by suitable absorption medium, for example absorbent in liquid phase, typically in aqueous solution. Gas is passed through the absorption medium under conditions of pressure and temperature optimised for removal of substantially all the carbon dioxide. The purified gas is then directed for further processing as necessary. The absorption medium rich in CO_2 is subjected to a stripping process to remove the CO_2 and regenerate the absorption medium.

Typically this process involves regenerative heating of the medium. The CO_2 rich medium is maintained at high temperature, which may be at or near boiling point of an absorbent liquid phase under pressure. The heat necessary is typically obtained when the system is used in association with a thermal power plant by supplying steam from the LP turbine system. At higher temperatures the medium will release the absorbed CO_2. Regenerated medium may be drawn off for reuse. The released CO_2 may then be collected for example for sequestration. The condensate product of the steam used to supply regenerative heat is returned to the steam generation system.

Steam is diverted from upstream of the LP turbine, for example, in the case where the system comprises HP, IP and LP turbines or turbine sets with combined HP/IP modules, from the vicinity of the IP/ LP crossover. The diverting of steam away from the LP turbine for carbon capture moves the regime of operation along the left of the exhaust loss curve. This can be seen with reference to the example exhaust loss curve of figure 1. If this point of operation moves to the left of the minimum point (A) in Figure 1, then exhaust loss increases tremendously, causing substantial loss of power generation.

It is desirable to develop a system and operational method by which the flow regime of the LP Turbine can move along the right of the exhaust loss curve and compensate the loss of generated power, along with providing the power plant operator the flexibility of determining the optimum regime of operation balancing the economics of power generation, heat rate and carbon capture.

In accordance with the invention there is provided a steam turbine system comprising fluidly in series:

at least one high pressure turbine; and/ or

at least one intermediate pressure turbine; and

at least one low pressure turbine;

and further comprising steam outlet means to enable extraction of auxiliary process steam from a location upstream of the low pressure turbine and for example between the intermediate pressure turbine and the low pressure turbine; and

at least one flow restrictor in a steam extraction conduit from the or each low pressure turbine to allow the variation of mass flows therefrom by suitable modification of pressures.

The invention draws process steam from a location upstream of the low pressure turbine, being a location between a low pressure turbine or turbine set and a higher pressure turbine or set upstream thereof and preferably first upstream thereof, being an intermediate pressure turbine or set where present.

In the preferred case the steam turbine system comprises fluidly in series at least one high pressure turbine, at least one intermediate pressure turbine, and at least one low pressure turbine and process steam is drawn from a location between the intermediate pressure turbine and the low pressure turbine and for example at or about the IP/LP crossover. The steam outlet means in the preferred case are located to enable extraction of auxiliary process steam from a location in the vicinity of the IP/LP crossover. The invention is distinctly characterised by the provision of flow restrictors in the LP Turbine Extraction which allows the variation of mass flows by suitable modification of pressures thereby moving the flow regime to the right of the exhaust loss curve, simultaneously providing the operator the means of responding to planned load changes and various unanticipated modes of power plant operation involving transients,

frequency support etc. This promotes stability of operation by moving the flow regime of LP Turbine along the right of Exhaust Loss Curve.

Process steam is drawn off to supply additional process module(s) with a source of motive power and/ or latent heat. The steam generator conveniently further comprises a fluid conduit fluidly continuous with the steam outlet means to convey auxiliary process steam to such additional process module(s).

The steam turbine system in particular comprises a generator for generation of steam from combustion of carbonaceous fuel, for example in a thermal power plant, and is preferably adapted for use with an associated means for post-combustion carbon capture.

In this preferred case, process steam is drawn off to supply an associated post combustion carbon capture plant with a source of motive power and/ or latent heat. The steam turbine system conveniently further comprises a fluid conduit fluidly continuous with the steam outlet means to convey auxiliary process steam to an associated post combustion carbon capture plant.

In a more complete aspect of the invention, it follows that a steam generator system with post-combustion carbon capture capability comprises:

a steam generator adapted in use to produce steam in use using thermal energy from combustion of carbonaceous fuel;

at least one high pressure turbine; and/ or

at least one intermediate pressure turbine; and

at least one low pressure turbine;

and further comprising steam outlet means to enable extraction of auxiliary process steam from a location upstream of the low pressure turbine and for example between the intermediate pressure turbine and the low pressure turbine;

at least one flow restrictor in a steam extraction conduit from the or each low pressure turbine;

a post-combustion carbon capture apparatus fluidly disposed to recover CO_2 from combustion gases generated by the combustion of carbonaceous fuel in use;

a fluid conduit fluidly continuous with the steam outlet means to convey auxiliary process steam to the post-combustion carbon capture apparatus.

Thus, in the more complete aspect of the invention, the steam generator system with post-combustion carbon capture capability conveniently comprises a steam turbine system in accordance with the first aspect of the invention in combination with a steam generator adapted in use to produce steam in use using thermal energy from combustion of carbonaceous fuel, a post-combustion carbon capture apparatus fluidly disposed to recover CO_2 from combustion gases generated by the combustion of carbonaceous fuel in use, and a fluid conduit fluidly continuous with the steam outlet means of the steam turbine system to convey auxiliary process steam to the post-combustion carbon capture apparatus.

Process steam is drawn off to supply the associated post combustion carbon capture plant with a source of motive power and/ or latent heat. In particular, process steam is drawn off to regenerate lean absorbent in a post-combustion carbon capture apparatus using absorbent medium such as absorbent solution, for example to supply latent heat to a re-boiler for lean solvent regeneration. Other supplies of auxiliary process steam may

be made available for example to the steam turbine auxiliary drive, and to the reclaimer for maintaining solver properties.

The person skilled in the art will be familiar with suitable power plant and PCC systems. The invention is not particularly limited to any such system.

The post-combustion carbon capture plant may for example comprise an absorber column where CO_2 is separated from the flue gas by means of absorption by passing the gas through a column where the gas flows in an opposite direction to an absorbent in liquid phase, typically in aqueous solution.

The post-combustion carbon capture plant may for example further comprise a regeneration column where CO_2 is removed from absorbent by regenerative heating, for example to at or near boiling point of an absorbent liquid phase under pressure. A suitable heating means is for example a condenser reboiler as is familiar. Again, as is familiar, this condenser reboiler may be disposed to receive solution that has passed through a process volume, for example via an outlet towards the bottom of a column, and reboil the solution to regenerate lean absorbent.

Conveniently, steam from the IP/ LP crossover is used to supply latent thermal energy for the above processes. It is a particular advantage of the invention that the introduction of a flow restrictor in the LP extraction line enables this process to be optimized in that it offers the necessary pressure control to promote stability of operation by moving the flow regime of LP Turbine along the right of Exhaust Loss Curve.

Any suitable flow restrictor can be incorporated into the LP steam extraction conduit provided that it can be modulated to maintain the

necessary pressure control. The flow restrictor is for example a valve. The flow restrictor may for example be selected from: a control valve, a globe valve with a suitably shaped and actuated plug, a butterfly valve with a suitably shaped and actuated disk, a non-return valve with a suitably shaped and actuated restriction.

In accordance with a further aspect, the invention may comprise a method of modification of a steam generator, in particular a generator for generation of steam from combustion of carbonaceous fuel, for example in a thermal power plant, comprising at least one high pressure turbine and/ or at least one intermediate pressure turbine, and at least one low pressure turbine; and for example adapted for use with an associated post-combustion carbon capture system.

The method comprises the steps of:
providing steam outlet means to enable extraction of auxiliary process steam from a location upstream of the low pressure turbine, for example to supply a post combustion carbon capture plant with a source of motive power and/ or latent heat;
incorporating a flow restrictor into a steam extraction conduit of the or each low pressure turbine to allow the variation of mass flows therefrom by suitable modification of pressures.

The method comprises in a first step providing steam outlet means to enable extraction of process steam from a location upstream of the at least one low pressure turbine, being a location between a low pressure turbine or turbine set and a higher pressure turbine or set. In the preferred case, the steam generator comprises at least one high pressure turbine and at least one intermediate pressure turbine and at least one low pressure turbine and the method comprises in a first step providing steam

outlet means to enable extraction of process steam from a location between the at least one intermediate pressure turbine and the at least one low pressure turbine for example in the vicinity of the IP/ LP crossover.

This aspect of the invention may comprise the two steps performed separately, or may comprise the second step performed subsequently on a steam generator already modified by the first step. The method is suitable for both green field projects and retro-fitting on a brown field project. Substantial parts of existing plants can be left untouched with no necessity for modification. In consequence in the preferred case the second aspect of the invention comprises a method of after-market modification of existing plant in situ by performance of the second foregoing step independently or of both the foregoing steps.

In accordance with a yet further aspect of the invention there is provided a method of operation of a steam turbine system of a steam generator having at least one high pressure turbine and/ or at least one intermediate pressure turbine and at least one low pressure turbine; and for example adapted for use with an associated post-combustion carbon capture system; the method comprising:

drawing auxiliary process steam from a location upstream of the low pressure turbine and for example between the intermediate pressure turbine and the low pressure turbine;

modifying the flow of steam extracted downstream of the low pressure turbine to move the flow regime from the LP turbine towards a more desired location on a notional Exhaust Loss Curve.

In particular, the second step is performed dynamically and simultaneously with the first to promote stability of operation by moving the flow regime of LP Turbine right along the Exhaust Loss Curve.

The second step may be performed by operation of a suitable flow restrictor such as a control valve in the LP turbine steam extraction conduit.

The method comprises drawing off auxiliary process steam from a location upstream of the at least one low pressure turbine, being a location between a low pressure turbine or turbine set and a higher pressure turbine or set. In the preferred case, where the steam generator comprises at least one high pressure turbine and at least one intermediate pressure turbine and at least one low pressure turbine, the method comprises drawing off auxiliary process steam from a location between the at least one intermediate pressure turbine and the at least one low pressure turbine for example in the vicinity of the IP/ LP crossover.

In the preferred case, auxiliary process steam is drawn to supply a post combustion carbon capture plant with a source of motive power and/ or latent heat.

In particular, the method is a method of operation of a steam turbine power plant having a post-combustion carbon capture plant which uses steam from the power plant for auxiliary purposes and for example as a latent heat source for regeneration of absorbent, and the method comprises circulating the process steam for such a purpose.

Other preferred aspects of the method will be understood by analogy to the foregoing.

The invention will now be described by way of example only with reference to Figures 1 to 3 of the accompanying drawings, in which:

Figure 1 a typical exhaust loss curve for a typical LP turbine;

Figure 2 is a general schematic of a prior art steam generator with PCC apparatus with unregulated LP steam extraction;

Figure 3 is a schematic showing the introduction of control valves to regulate mass flow in steam extraction from the LP turbines of a typical steam generator in accordance with the principles of the invention.

Figure 1 is a general schematic of a thermal power plant with HP, IP and LP turbine systems, and with a PCC system for capture of CO_2 from the combustion flue gases supplied by process steam from the IP/ LP crossover of the steam generation system. Such a system is representative of a typical plant to which the principles of the invention may be applied.

Figure 1 describes the typical family of exhaust loss curves of a family of Low Pressure Steam Turbines, involving increasing heights of Last Stage Blades (LSB's); as moving from left to right.

The preferred regime of operation is to the right of the minimum point ("A") for any particular family of Low Pressure Turbine.

The diverting of steam away from the LP turbine for carbon capture moves the regime of operation along the left of the exhaust loss curve. If this point of operation moves to the left of the minimum point (A) in Figure 2, then exhaust loss increases tremendously, causing substantial loss of power generation.

Figure 2 is an example of a prior art system with uncontrolled extraction lines from LP turbines and with steam extraction for PCC.

In the example, a steam generator comprises at least one high pressure turbine and/ or at least one intermediate pressure turbine and at least one low pressure turbine. Two are shown. The diagram in figure 2 shows elements downstream of the HP/ IP sets. The arrangement of the HP/ IP sets and other elements of the system will be familiar to those skilled in the art and the invention is not specific to any such arrangement. The arrangement includes steam extraction to supply a post combustion carbon capture plant (PCC).

Steam passes from the HP/ IP sets in the direction of the arrow S. Steam necessary to recover carbon dioxide from a rich amine solution in a post combustion carbon capture plant (PCC) is sourced via the line 11 upstream of the LP set, for example at the IP/ LP crossover. The remaining steam for extraction (apart from final exhaust) passes via LP turbines LP1, LP2 through uncontrolled extraction conduits 13a, 13b.

Steam is optimally sourced from the IP/LP cross-over for optimal heat exchange. However, steam diverted away from the LP Turbine with uncontrolled extractions results in lowering of pressure upstream of LP Turbine on account of constant vacuum downstream.

Figure 3 shows a possible embodiment of the invention to mitigate this problem.

In the example shown in figure 3, a similar steam generator comprises again at least one high pressure turbine and/ or at least one intermediate pressure turbine and at least one low pressure turbine. Two are shown.

The figure again shows elements downstream of the HP/ IP sets but the remaining arrangement will be familiar.

Steam again passes from the HP/ IP sets in the direction of the arrow S. PCC steam is sourced from the IP/ LP crossover via the line 21. The remaining steam for extraction (apart from final exhaust) passes via LP turbines LP1, LP2 through uncontrolled extraction conduits 23a, 23b.

The embodiment is modified by provision of flow restrictors (in the example the control valves 25a, 25b) incorporated into the LP turbine extraction lines. The figure shows an optimum location of the control valves in the LP turbine extraction lines, which allow the control of pressures and thereby mass flows within the LP turbines thereby enabling the flow regime to move towards the right of the Exhaust Flow Curve when steam is tapped from the IP/LP Crossover for example for carbon capture such as in the example system of figure 1.

The introduction of controlled extractions reduces the exhaust loss of steam passing out of LP Turbine for a wide variety of operational load cases. This provides the power plant operator the flexibility of determining the optimum regime of operation balancing the economics of power generation, heat rate and carbon capture.

This method promotes stability of operation by moving the flow regime of LP Turbine along the right of Exhaust Loss Curve.

This method Compensates against loss of power incurred for diverting steam to PCC.

This method provides operational flexibility of determining optimum regime vis-à-vis power, heat rate and carbon capture.

CLAIMS

1. A steam turbine system comprising fluidly in series:
   at least one high pressure turbine; and/ or
   at least one intermediate pressure turbine; and
   at least one low pressure turbine;
   and further comprising steam outlet means to enable extraction of auxiliary process steam from a location upstream of the low pressure turbine; and
   at least one flow restrictor in a steam extraction conduit from the or each low pressure turbine.

2. A steam turbine system in accordance with claim 1 wherein the steam outlet means are located to enable extraction of auxiliary process steam from a location between at least one low pressure turbine and a higher pressure turbine upstream thereof.

3. A steam turbine system in accordance with claim 2 comprising at least one high pressure turbine and at least one intermediate pressure turbine and at least one low pressure turbine wherein the steam outlet means are located to enable extraction of auxiliary process steam from a location between at least one low pressure turbine and at least one intermediate pressure turbine.

4. A steam turbine system in accordance with claim 3 wherein the steam outlet means are located to enable extraction of auxiliary process steam from a location in the vicinity of the IP/LP crossover.

5. A steam turbine system in accordance with any preceding claim wherein the steam turbine system further comprises one or more fluid conduits fluidly continuous with the steam outlet means to convey auxiliary process steam to additional process module(s) as a source of motive power and/ or latent heat.

6. A steam turbine system in accordance with claim 5 comprising fluid conduit fluidly continuous with the steam outlet means to convey auxiliary process steam to an associated post combustion carbon capture plant.

7. A steam turbine system in accordance with any preceding claim comprising a generator for generation of steam from combustion of carbonaceous fuel, and adapted for use with an associated means for post-combustion carbon capture.

8. A steam generator system with post-combustion carbon capture capability comprising:
a steam generator to produce steam from combustion of carbonaceous fuel;
a steam turbine system in accordance with any preceding claim;
a post-combustion carbon capture apparatus fluidly disposed to recover CO_2 from combustion gases generated by the combustion of carbonaceous fuel in use;
a fluid conduit fluidly continuous with the steam outlet means to convey auxiliary process steam to the post-combustion carbon capture apparatus.

9. A system in accordance with claim 8 wherein the post-combustion carbon capture system comprises an absorber column where CO_2

is separated from the flue gas by means of absorption by passing the gas through a column where the gas flows in an opposite direction to an absorbent in liquid phase.

10. A system in accordance with claim 8 or 9 wherein the post-combustion carbon capture system further comprises a regeneration column where CO_2 is removed from absorbent by regenerative heating.

11. A system in accordance with claim 10 comprising a condenser reboiler is disposed to receive absorbent solution and reboil the solution to regenerate lean absorbent.

12. A system in accordance with any preceding claim wherein the flow restrictor is a valve.

13. A system in accordance with claim 12 wherein the flow restrictor is selected from: a control valve, a globe valve with a suitably shaped and actuated plug, a butterfly valve with a suitably shaped and actuated disk, a non-return valve with a suitably shaped and actuated restriction.

14. A method of modification of a steam generator comprising at least one high pressure turbine and/ or at least one intermediate pressure turbine and at least one low pressure turbine;
the method comprising the step of:
incorporating a flow restrictor into a steam extraction conduit of the or each low pressure turbine to allow the variation of mass flows therefrom by suitable modification of pressures.

15. A method of modification of a steam generator in accordance with claim 14 comprising the additional step of:
providing steam outlet means to enable extraction of auxiliary process steam from a location upstream of the low pressure turbine, for example to supply a post combustion carbon capture plant with a source of motive power and/ or latent heat.

16. The method of claim 14 or 15 performed as a method of after-market modification of existing plant in situ.

17. A method of operation of a steam turbine system having at least one high pressure turbine and/ or at least one intermediate pressure turbine and at least one low pressure turbine comprising:
drawing auxiliary process steam from a location upstream of the low pressure turbine;
modifying the flow of steam extracted downstream of the low pressure turbine to move the flow regime from the LP turbine towards a more desired location on a notional Exhaust Loss Curve.

18. The method of claim 17 wherein the step of modifying the flow of steam extracted downstream of the low pressure turbine is performed dynamically and simultaneously with the step of drawing auxiliary process steam to promote stability of operation by moving the flow regime of LP Turbine right along the Exhaust Loss Curve.

19. The method of claim 18 wherein the step of modifying the flow of steam extracted downstream of the low pressure turbine is performed by operation of a suitable flow restrictor such as a control valve in the LP turbine steam extraction conduit.

20. The method of one of claims 17 to 19 wherein the steam generator comprises at least one high pressure turbine and at least one intermediate pressure turbine and at least one low pressure turbine, and the method comprises drawing off auxiliary process steam from a location between the at least one intermediate pressure turbine and the at least one low pressure turbine.

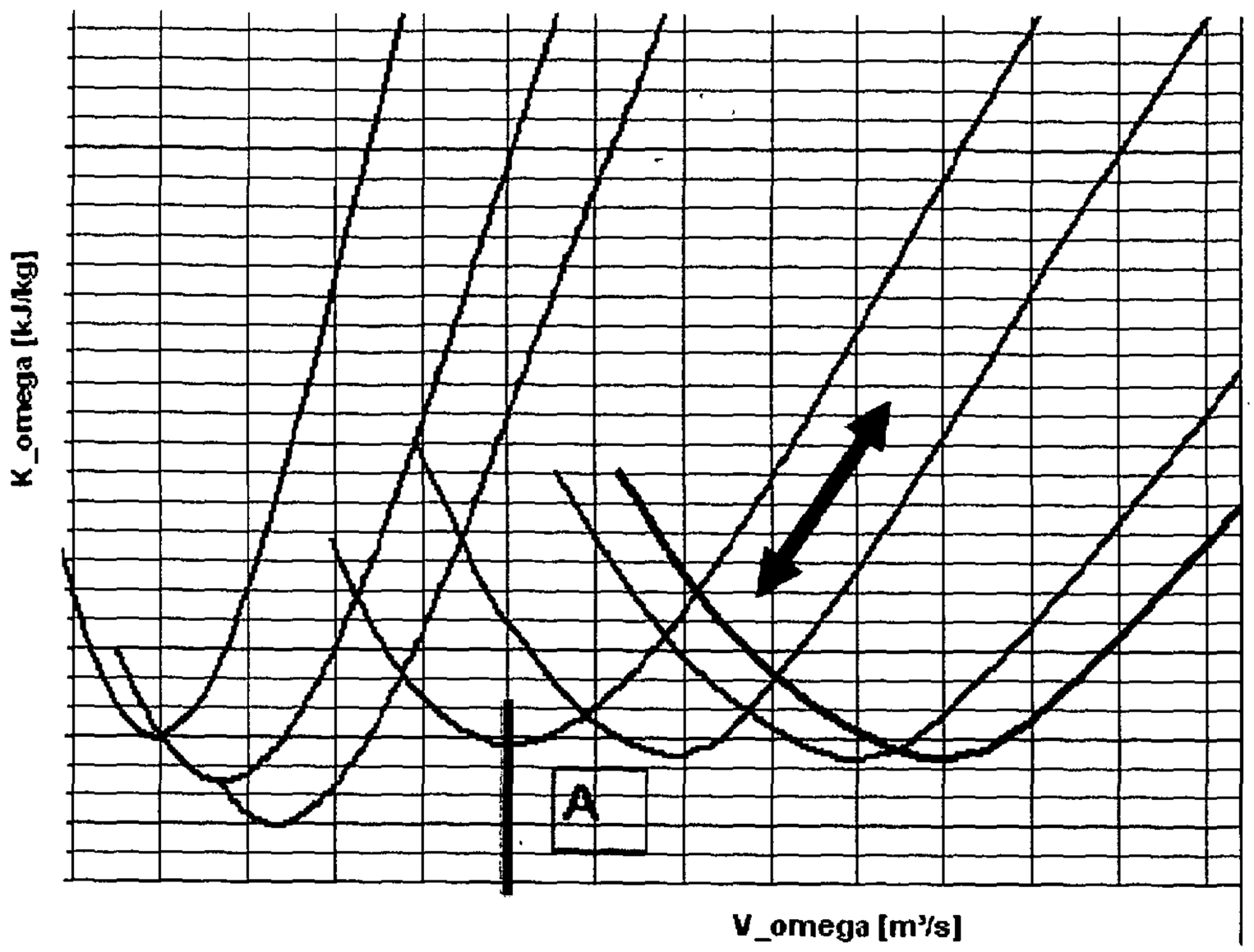


Figure 1

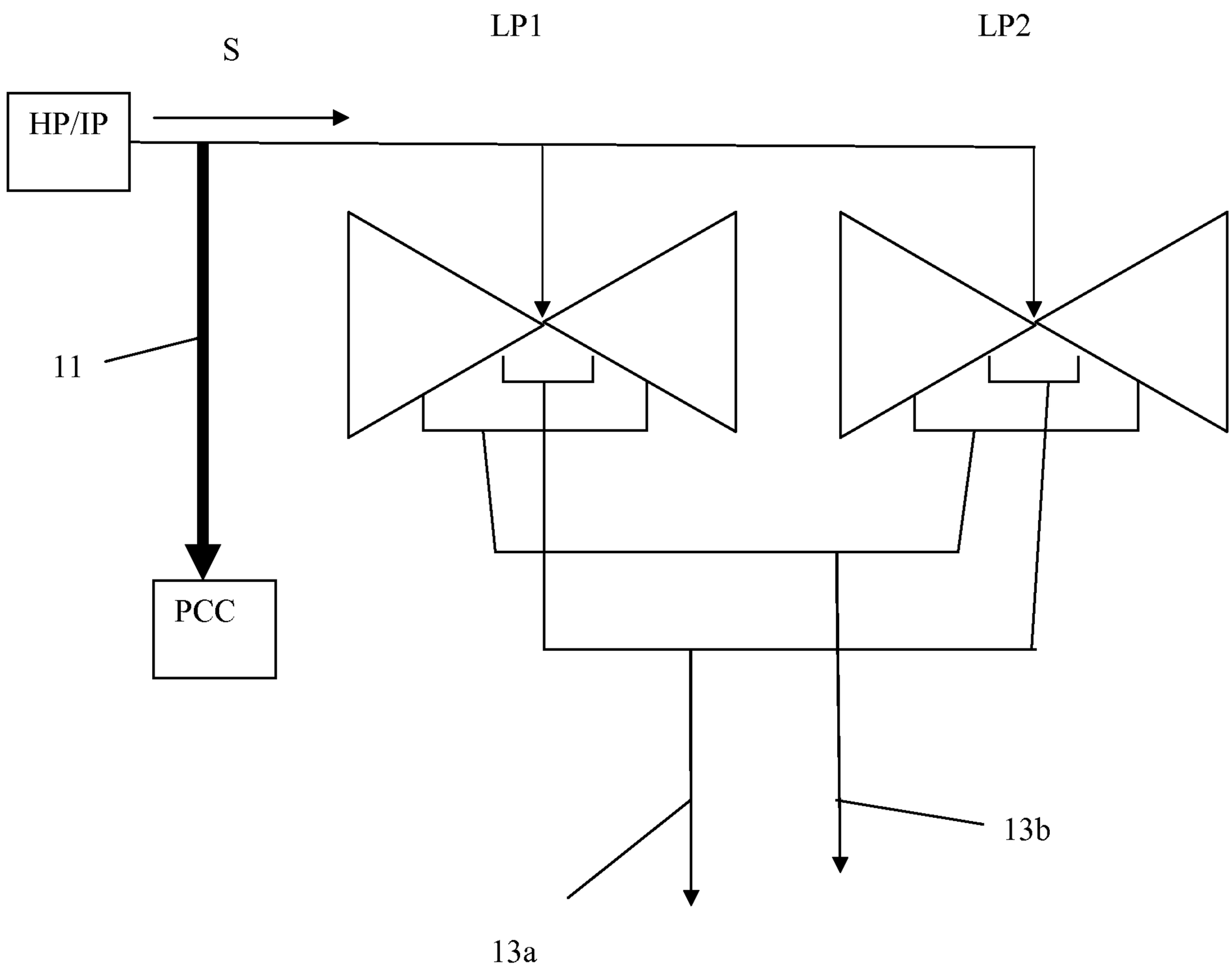


Figure 2 – Prior Art

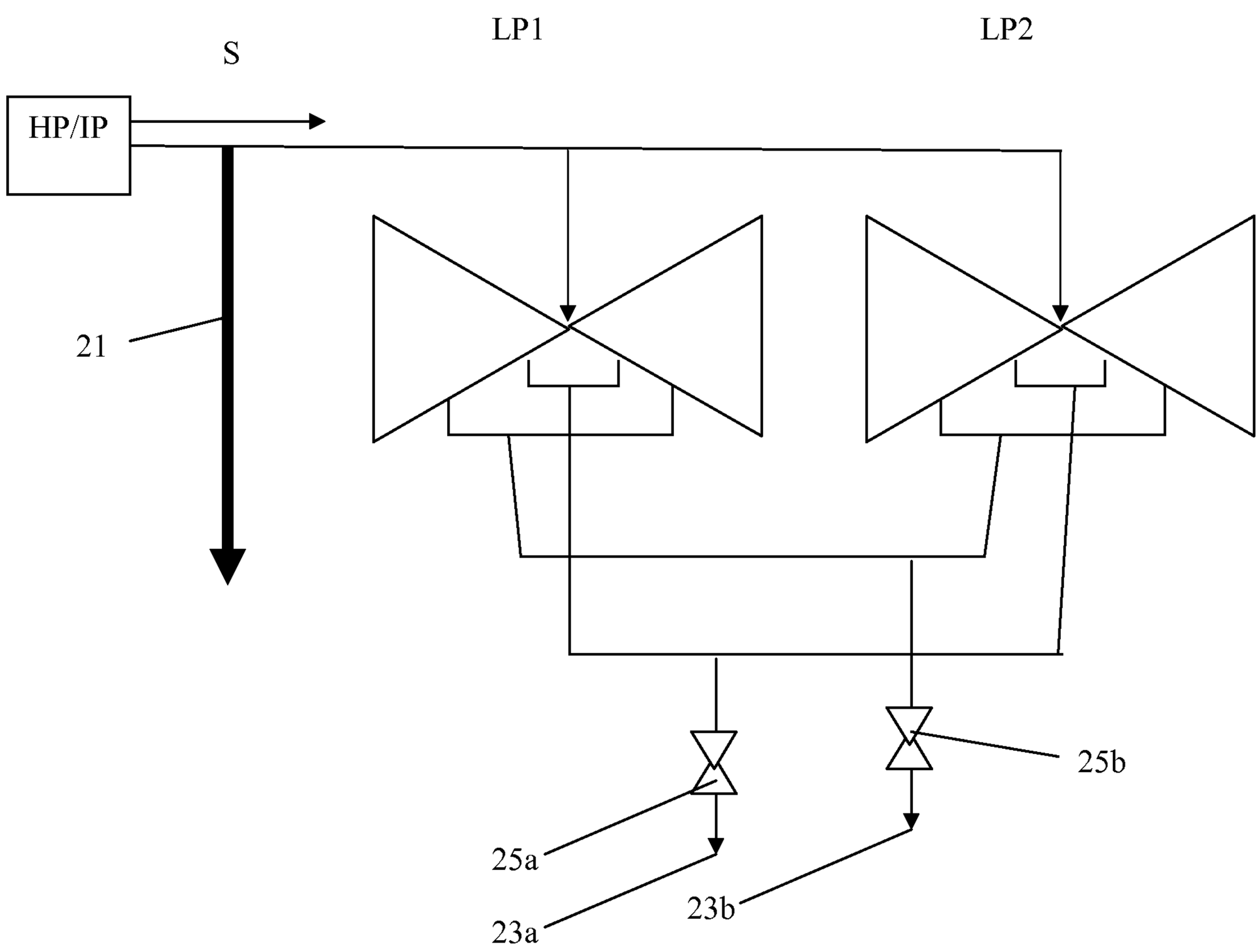


Figure 3

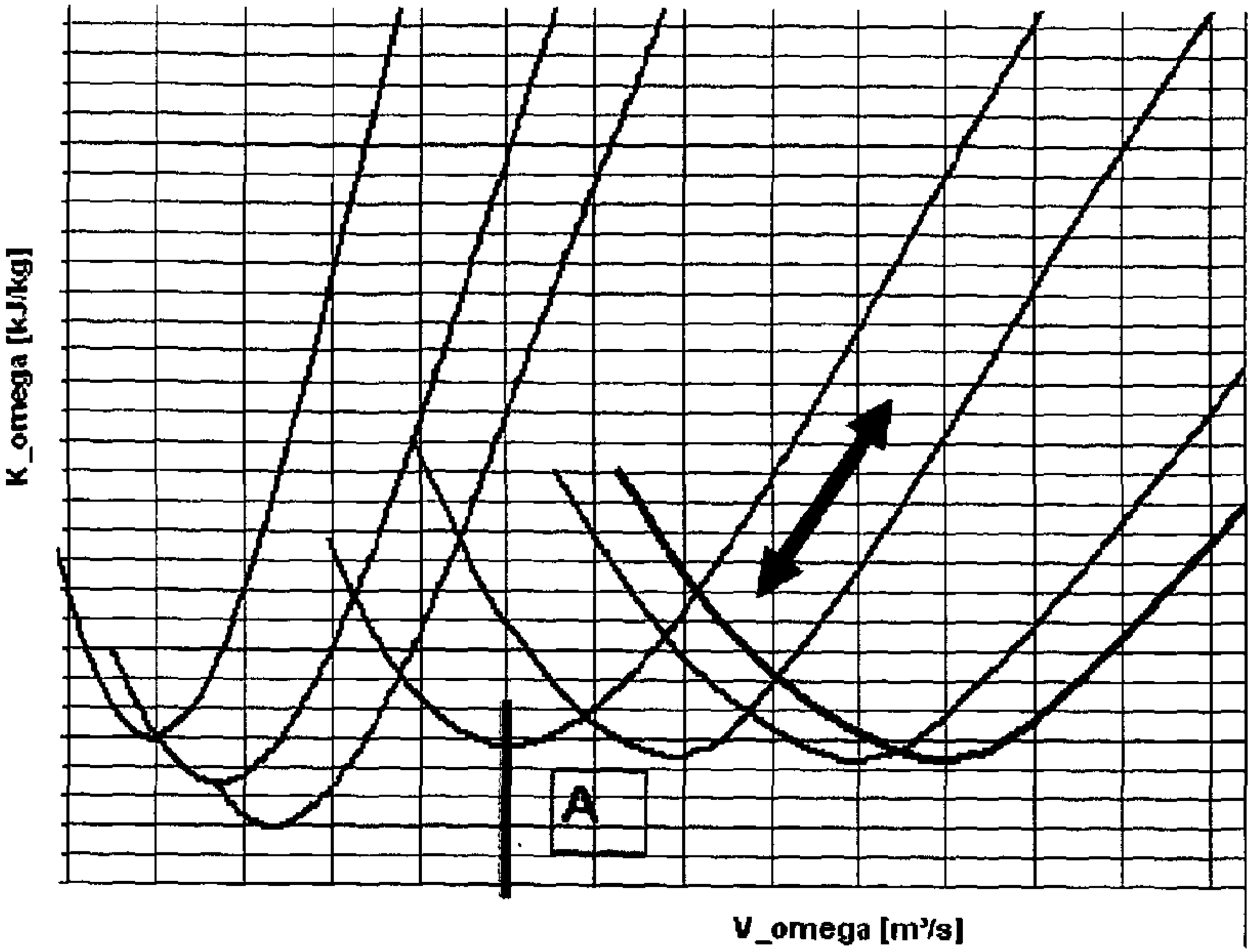


Figure 1