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(54) Title: A METHOD FOR CONTROLLING A SUPPLY OF REFRIGERANT TO AN EVAPORATOR BASED ON TEMPERATURE MEASUREMENTS

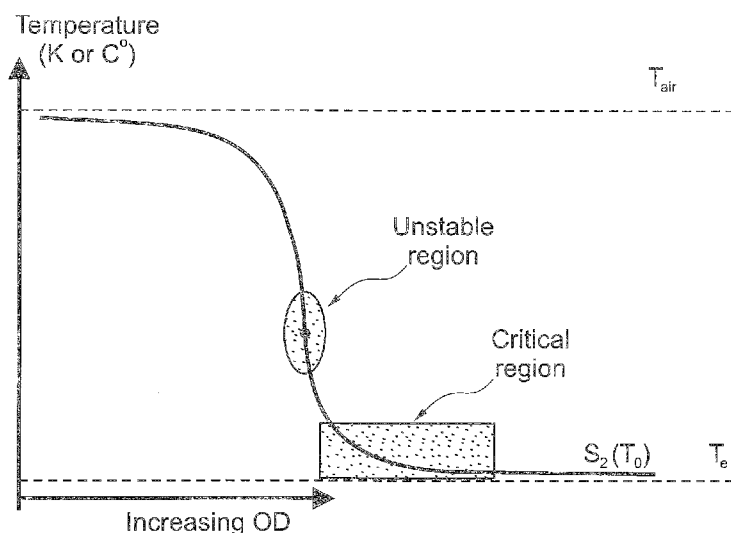


Fig. 1

(57) Abstract: A method for controlling a supply of refrigerant to an evaporator (2) of a vapour compression system (1), such as a refrigeration system, an air condition system or a heat pump. The opening degree of the expansion valve (3) is controlled on the basis of an air temperature, T_{air} , of air flowing across the evaporator (2), and in order to reach a reference air temperature, $T_{air, ref}$. The opening degree is set to the calculated opening degree, overlaid with a perturbation signal. A temperature signal, S_2 , representing a temperature of refrigerant leaving the evaporator (2) is monitored and analysed. In the case that the analysis reveals that a dry zone of the evaporator (2) is approaching a minimum length, the opening degree of the expansion valve (3) is decreased. This provides a safety mechanism which ensures that liquid refrigerant is prevented from passing through the evaporator (2).

A METHOD FOR CONTROLLING A SUPPLY OF REFRIGERANT TO AN EVAPORATOR BASED ON TEMPERATURE MEASUREMENTS

FIELD OF THE INVENTION

The present invention relates to a method for controlling a supply of refrigerant to an evaporator, in particular to an evaporator which forms part of a vapour compression system, such as a refrigeration system, an air condition system or a heat pump. According to the method of the present invention, the supply of refrigerant to the evaporator can be controlled in a manner which provides a desired target temperature in a refrigerated or heated volume, while preventing liquid refrigerant from entering the suction line, and based solely on temperature measurements.

BACKGROUND OF THE INVENTION

Vapour compression systems, such as refrigeration systems, air condition systems or heat pumps, normally comprise at least one compressor, at least one condenser, at least one expansion device, e.g. in the form of expansion valves, and at least one evaporator arranged along a refrigerant path. Refrigerant circulates the refrigerant path and is alternately expanded and compressed, and heat exchange takes place in the condensers and the evaporators. Expanded refrigerant enters the evaporators in a mixed state of gaseous and liquid refrigerant. As the refrigerant passes through the evaporators, it evaporates while exchanging heat with a secondary fluid flow, such as an air flow, across each evaporator. In order to utilise the potential refrigerating capacity of a given evaporator to a maximum extent, it is desirable that liquid refrigerant is present along the entire length of the evaporator. On the other hand, it is undesirable that liquid refrigerant passes through the evaporator and into the suction line, since it may cause damage to the compressors if liquid refrigerant reaches the compressors. It is therefore desirable to control the supply of refrigerant to the evaporators in such a manner that, in a given evaporator, the boundary between mixed phase refrigerant and gaseous refrigerant is exactly at the outlet of the evaporator.

In order to obtain this, the superheat of the refrigerant leaving the evaporators is often measured and/or calculated. The superheat is the difference between the temperature of the refrigerant leaving the evaporator and the dew point of the refrigerant leaving the evaporator. A low superheat value, thus, indicates that the temperature of the refrigerant leaving the evaporator is close to the dew point, while a high superheat value indicates that the temperature of the refrigerant leaving the evaporator is significantly higher than the dew point, and that a significant part of the evaporator therefore contains gaseous refrigerant. In

the part of the evaporator which contains gaseous refrigerant, the heat transfer between the ambient and the refrigerant flowing in the evaporator is significantly lower than in the part of the evaporator which contains a mixture of gaseous and liquid refrigerant. Therefore the overall efficiency of the evaporator is reduced when a significant part of the evaporator contains gaseous refrigerant. It is then attempted to control the supply of refrigerant to the evaporator in such a manner that the superheat value is maintained at a small, but positive, level.

In order to obtain the superheat value of refrigerant leaving the evaporator, the temperature as well as the pressure of the refrigerant leaving the evaporator is normally measured. The pressure sensor required in this case introduces the risk that the pressure sensor falls out or malfunctions, thereby making it impossible to measure the superheat value until the pressure sensor is restored. Furthermore, the pressure sensor introduces the risk of leaks in the system.

WO 2012/052019 A1 describes a method for controlling a supply of refrigerant to an evaporator, in which the $SH=0$ point can be determined purely on the basis of a measured temperature signal. A component, such as an expansion valve, a fan or a compressor, is actuated in such a manner that a dry zone of the evaporator is changed. A temperature signal, representing a temperature of refrigerant leaving the evaporator is measured and analysed, e.g. including deriving a rate of change signal. Then a temperature value where a gain of a transfer function between the actuated component and the measured temperature signal drops from a maximum value to a minimum value is determined. The determined temperature value is defined as corresponding to a zero superheat value ($SH=0$).

DESCRIPTION OF THE INVENTION

It is an object of embodiments of the invention to provide a method for controlling a supply of refrigerant to an evaporator, in which the supply of refrigerant is normally controlled to provide a predefined target temperature in a refrigerated or heated volume, while a safety mechanism prevents that liquid refrigerant reaches the compressor.

It is a further object of embodiments of the invention to provide a method for controlling a supply of refrigerant to an evaporator during a pull down process, in which a fast pull down is ensured, while it is prevented that liquid refrigerant reaches the compressor.

According to a first aspect the invention provides a method for controlling a supply of refrigerant to an evaporator of a vapour compression system, the vapour compression system comprising at least one evaporator, at least one compressor, at least one condenser

and at least one expansion valve arranged in a refrigerant circuit, the method comprising the steps of:

- obtaining a temperature, T_{air} , of air flowing across the evaporator,
- 5 – controlling an opening degree of the expansion valve, on the basis of the obtained temperature, T_{air} , and in order to reach a reference air temperature, $T_{air, refr}$, of the air flowing across the evaporator,
- providing a perturbation signal, and setting the opening degree of the expansion valve to the controlled opening degree, overlaid with the perturbation signal,
- 10 – monitoring a temperature signal, S_2 , representing a temperature of refrigerant leaving the evaporator,
- analysing the temperature signal, S_2 , and
- decreasing the opening degree of the expansion valve in the case that said analysis reveals that a dry zone of the evaporator is approaching a minimum length.

15 In the present context the term 'vapour compression system' should be interpreted to mean any system in which a flow of fluid medium, such as refrigerant, circulates and is alternately compressed and expanded, thereby providing either refrigeration or heating of a volume. Thus, the vapour compression system may be a refrigeration system, an air condition system, a heat pump, etc.

20 The vapour compression system comprises at least one evaporator, at least one compressor, at least one condenser, and at least one expansion valve. Thus, the vapour compression system may comprise only one of each of these components, or the vapour compression system may comprise two or more of any of these components. For instance, the vapour compression system may comprise a single compressor, or it may comprise two or more compressors, e.g. arranged in a compressor rack. Similarly, the vapour compression system
25 may comprise only one evaporator, or it may comprise two or more evaporators. In the latter case each evaporator may be arranged to provide refrigeration for a separate refrigerated volume. The separate refrigerated volumes may, e.g., be separate display cases of a supermarket. In any event, each evaporator is preferably connected to a separate expansion valve which controls the supply of refrigerant to that evaporator, independently of the
30 refrigerant supply to the other evaporators. Furthermore, an evaporator unit may comprise a single section, or two or more sections which may be connected in series or in parallel.

The method according to the first aspect of the invention is related to control of the supply of refrigerant to a single evaporator, via the corresponding expansion valve. However, this evaporator may very well be arranged in a vapour compression system comprising one or more additional evaporators, in which case the supply of refrigerant to these additional
5 evaporators is controlled separately.

According to the method according to the first aspect of the invention a temperature, T_{air} , of air flowing across the evaporator is initially obtained. This may preferably be done by means of one or more temperature sensors arranged in an air passage across the evaporator. The temperature, T_{air} , could, e.g. be the temperature of air flowing towards the evaporator, the
10 temperature of air flowing away from the evaporator, or a weighted value of the temperature of air flowing towards the evaporator and the temperature of air flowing away from the evaporator. This will be described in further detail below. In any event, T_{air} represents a temperature prevailing in a refrigerated volume arranged near the evaporator. Accordingly, T_{air} reflects a cooling need of the refrigerated volume.

15 Next, an opening degree of the expansion valve is controlled on the basis of the obtained temperature, T_{air} , and in order to reach a reference air temperature, $T_{air, ref}$, of the air flowing across the evaporator. As described above, T_{air} reflects a temperature prevailing in the refrigerated volume, and thereby a cooling need of the refrigerated volume. The reference air temperature, $T_{air, ref}$, is a target temperature, which it is desired to obtain in the refrigerated
20 volume. Thus, by comparing the obtained temperature, T_{air} , to the reference air temperature, $T_{air, ref}$, it can be revealed whether the prevailing temperature in the refrigerated volume is close to or far away from the desired target temperature. In the case that the prevailing temperature is far away from the target temperature, further cooling is highly needed, and the supply of refrigerant to the evaporator should be such as to provide as much cooling as
25 possible. Similarly, in the case that the prevailing temperature is close to the desired target temperature, the need for further cooling is somewhat lower, and the supply of refrigerant to the evaporator can be controlled in a manner which provides less cooling, but which instead ensures a low energy consumption.

Thus, under normal circumstances the supply of refrigerant to the evaporator is controlled
30 solely in a manner which ensures that a desired target temperature in the refrigerated volume is obtained.

It should be noted that increasing the opening degree of the expansion valve results in an increase in the supply of refrigerant to the evaporator, and decreasing the opening degree of the expansion valve results in a decrease in the supply of refrigerant to the evaporator.

- Next, a perturbation signal is provided, and the opening degree of the expansion valve is set to the controlled opening degree, overlaid with the perturbation signal. Thus, the opening degree of the expansion valve fluctuates around a mean value, which represents the controlled opening degree, i.e. the opening degree which is dictated by the obtained temperature, T_{air} . The fluctuations are determined by the perturbation signal, and may, e.g., be sinusoidal, of a relay type, or of any other suitable type. This will be described in further detail below. In the present context the term 'perturbation signal' should be interpreted to mean a signal which varies on a time scale, which is significantly shorter than the time scale on which the controlled opening degree of the expansion valve varies.
- 10 Then a temperature signal, S_2 , representing a temperature of refrigerant leaving the evaporator is monitored. This may, e.g., be done using a temperature sensor arranged in the refrigerant path immediately after the outlet of the evaporator. Thus, the temperature signal, S_2 , represents a relative value of the superheat value of the refrigerant leaving the evaporator. The monitored temperature signal, S_2 , is analysed.
- 15 Finally, the opening degree of the expansion valve is decreased in the case that the analysis of the monitored temperature signal, S_2 , reveals that a dry zone of the evaporator is approaching a minimum length.

In the present context the term 'dry zone of the evaporator' should be interpreted to mean a part of the evaporator containing only gaseous refrigerant. A dry zone of a long length thereby indicates that liquid refrigerant is evaporated in the evaporator well before reaching the evaporator outlet, while a dry zone of a short length indicates that liquid refrigerant is present along a substantial part of the evaporator. Accordingly, when the dry zone of the evaporator approaches a minimum length, then the boundary between the mixed liquid/gaseous refrigerant and the purely gaseous refrigerant is approaching the outlet of the evaporator. As described above, when this boundary reaches the outlet of the evaporator there is a risk that liquid refrigerant is allowed to pass through the evaporator, and thereby there is a risk that liquid refrigerant reaches the compressor, thereby causing damage to the compressor. Therefore, when the dry zone of the evaporator approaches a minimum length, the supply of refrigerant to the evaporator must be decreased in order to avoid this situation.

- 30 Whether or not the dry zone of the evaporator is approaching a minimum length can be established in a number of ways. It has been found by the inventors of the present invention that when the dry zone of the evaporator approaches a minimum length, the behaviour of the temperature signal, S_2 , changes in a significant manner. Thus, when analysing the temperature signal, S_2 , signs of these changes may be detected. For instance, the inventors of the present invention have found that if the opening degree of the expansion valve is
- 35

slowly increased, then the temperature of the refrigerant leaving the evaporator will decrease abruptly when the opening degree of the expansion valve reaches a level, where the supply of refrigerant to the evaporator is sufficient to reduce the dry zone of the evaporator to the minimum length. This may be regarded as an 'unstable region'. If the opening degree is
5 increased even further, there is a significant risk that liquid refrigerant is passed through the evaporator. This may be regarded as a 'critical region'.

Thus, the step of analysing the temperature signal, S_2 , may comprise obtaining a rate of change of the temperature signal, S_2 , and the step of decreasing the opening degree may comprise decreasing the opening degree of the expansion valve in the case that an absolute
10 value of the rate of change of the temperature signal, S_2 , reaches a maximum value, such as a global or a local maximum. As described above, the temperature signal, S_2 , decreases abruptly, when the unstable region is entered. Thus, when the absolute value of the rate of change of the temperature signal, S_2 , reaches the maximum value, it can be concluded that the unstable region has been entered, and that the dry zone of the evaporator is therefore
15 approaching the minimum length. The actual maximum value is not a fixed or unique value, but may change depending on the operating point. However, an extreme of the signal will be reached, since the curve defines a saddle point, and it is this saddle point, which indicates that the unstable region has been entered.

Before reaching the unstable region, the signal, S_2 , follows a concave curve, in the middle of
20 the unstable region there is a saddle point, and from the unstable region until the evaporator is completely flooded, the signal, S_2 , follows a convex curve. On the concave part of the curve, the rate of change of the signal is negative and becomes smaller the closer it gets to the saddle point. At the saddle point, the rate of change of the signal, S_2 , reaches its minimum. Hence, by computing the minimum of the rate of change of the signal, S_2 , the
25 saddle point, which represents the centre of the unstable region, can be identified. As the expansion valve is largely open while this process is being carried out, it is obvious that the dry zone of the evaporator approaches its minimum length. Accordingly, the opening degree of the expansion valve must be decreased, at this point, in order to avoid entering the critical region.

30 As an alternative, the step of analysing the temperature signal, S_2 , may comprise the steps of:

- Identifying a component of the temperature signal, S_2 , corresponding to the perturbation signal,

- comparing the identified component of the temperature signal, S_2 , to the original perturbation signal, and
- determining whether or not the dry zone of the evaporator is approaching a minimum length, based on said comparison.

5 The component of the temperature signal, S_2 , could, e.g., be variations in the temperature signals, S_2 , which corresponds to the variations in the opening degree which are defined by the perturbation signal and/or specific frequency components of the signal. For instance, in the case that the perturbation signal is a sinusoidal signal, the component could, e.g., be a frequency component with substantially the same frequency as the sinusoidal perturbation
10 signal, or with a different frequency. For instance, the component could be a frequency component which is a sum of several sinusoidal signals.

Comparing the identified component of the temperature signal, S_2 , to the original perturbation signal, reveals in which manner the perturbations applied to the opening degree of the expansion valve affects the monitored temperature signal, S_2 . The comparison could
15 be an actual comparison between the perturbation signal and the identified component. Alternatively, it could be a comparison between corresponding characteristics of the two signals, such as frequency and/or amplitude.

It has been found by the inventors of the present invention that the manner in which the perturbations applied to the opening degree of the expansion valve affects the monitored
20 temperature signal, S_2 , changes significantly, when the unstable region is entered, and the dry zone of the evaporator is therefore approaching a minimum length. If signs of such significant changes are detected during the analysis of the temperature signal, S_2 , it can therefore be concluded that the dry zone of the evaporator is approaching a minimum length, and accordingly the opening degree of the expansion valve must be decreased in order to
25 prevent that liquid refrigerant reaches the compressor.

For instance, in the case that the identified component of the perturbation signal is a main frequency, then the temperature signal, S_2 , may contain the main frequency as well as one or more additional frequency components, e.g. corresponding to harmonics of the main frequency. Performing a Fast Fourier Transform (FFT) of the temperature signal, S_2 , will
30 result in a number of parameters, corresponding to the additional frequency components. The sign of these parameters will change when the saddle point, as described above, is reached, i.e. when the unstable region is reached. Thus, when a change in sign of the parameters is detected, the opening degree of the expansion valve must be decreased in order to avoid that liquid refrigerant reaches the compressor.

The step of comparing the identified component of the temperature signal, S_2 , to the original perturbation signal may comprise determining a distortion of the identified component of the temperature signal, S_2 . In some cases the distortion of the component may change significantly when the unstable region is entered. Thus, when such changes are detected, it
5 can be concluded that the dry zone of the evaporator is approaching a minimum length, and that the opening degree of the expansion valve must therefore be decreased in order to prevent that liquid refrigerant reaches the compressor. The distortion could, e.g., include that the perturbation signal is a perfect sinusoidal signal, while the identified component is a fluctuation of the temperature signal, with a frequency which may be similar to the frequency
10 of the sinusoidal perturbation signal, but which is not a perfect sinusoidal signal. As an alternative, the distortion could be a combination of several frequencies that are multipliers of the original perturbation signal's frequency.

As another alternative, the step of analysing the temperature signal, S_2 , may comprise identifying one or more statistical components of the temperature signal, S_2 . The statistical
15 components could, e.g., include a mean value, a variance, etc., of the signal. Or the statistical component could include other descriptors of the probability distribution in the temperature signal, S_2 . For instance, when the temperature signal, S_2 , approaches the unstable region, the variance of the temperature signal, S_2 , increases. Similarly, when the temperature signal, S_2 , moves away from the unstable region, the corresponding variance
20 tends to decrease significantly.

The perturbation signal may be a sinusoidal type signal. In this case the opening degree of the expansion valve fluctuates in a substantially sinusoidal manner about the opening degree value which is dictated by the temperature, T_{air} , of air flowing across the evaporator. The frequency of the sinusoidal perturbation signal may be recognised in the monitored
25 temperature signal, S_2 .

As an alternative, the perturbation signal may be a relay type signal. In this case the opening degree of the expansion valve fluctuates in a relay-like manner, or as a square signal, about the opening degree value which is dictated by the temperature, T_{air} , of air flowing across the evaporator.

30 As another alternative, the perturbation signal may be of any other suitable kind, preferably a periodical signal, e.g. a triangular signal.

The temperature, T_{air} , may be a temperature of air flowing towards the evaporator. According to this embodiment, the opening degree of the expansion valve is controlled on the basis of a temperature which is prevailing in air in a refrigerated volume, before the air is passed across

the evaporator and thereby cooled. It can be assumed that this temperature varies relatively slowly, since it represents the temperature in the entire refrigerated volume.

As an alternative, the temperature, T_{air} , may be a temperature of air flowing away from the evaporator. According to this embodiment, the opening degree of the expansion valve is also
5 controlled on the basis of a temperature which is prevailing in air in a refrigerated volume. However, in this case the temperature is measured in air which has just passed across the evaporator, and which has therefore just been cooled by the evaporator. Accordingly, this temperature will not only reflect the temperature prevailing in the entire refrigerated volume, but will also reflect the instantaneous cooling power of the evaporator, since a high cooling
10 power will reduce this temperature. Thus, according to this embodiment the instantaneous cooling power of the evaporator is taken into account when controlling the opening degree of the expansion valve.

As another alternative, the temperature, T_{air} , may represent a weighted value of a temperature of air flowing towards the evaporator and a temperature of air flowing away
15 from the evaporator. According to this embodiment, the instantaneous cooling power of the evaporator is also taken into account when controlling the opening degree of the expansion valve. However, in this case the impact on the controlled opening degree is smaller than in the embodiment described above.

The method may further comprise the step of performing a pull down process in the case that
20 the temperature, T_{air} , of air flowing across the evaporator is above a predefined upper threshold value. If the temperature, T_{air} , exceeds the predefined upper threshold value, it may be assumed that the difference between the actual air temperature, T_{air} , and the target temperature or reference temperature, $T_{air, ref}$, is relatively large, i.e. that T_{air} is significantly higher than $T_{air, ref}$. In this case it may be necessary to reduce the actual air temperature, T_{air} ,
25 quickly, in order to be able to reach $T_{air, ref}$ within a reasonable time period. This may be obtained by performing a pull down process in this case. In the present context the term 'pull down process' should be interpreted to mean a process which applies a maximum, or at least very high, cooling power in order to pull down, or reduce, the air temperature inside the refrigerated volume quickly. It may, e.g., be relevant to perform a pull down process when
30 the system is initially started, or when new products have been positioned in the refrigerated volume.

The step of performing a pull down process may comprise the steps of:

- opening the expansion valve to a maximum opening degree,

- monitoring a temperature signal, S_2 , representing a temperature of refrigerant leaving the evaporator,
- analysing the temperature signal, S_2 , and
- 5 - decreasing the opening degree of the expansion valve in the case that said analysis reveals that an absolute value of a rate of change of the temperature signal, S_2 , has reached a maximum value.

Opening the expansion valve to a maximum opening degree ensures that the evaporator is filled as fast as possible, and thereby it is ensured that a maximum cooling power is provided. However, this also includes a risk that liquid refrigerant is allowed to pass through the evaporator, and potentially reach the compressor.

Therefore a temperature signal, S_2 , representing a temperature of refrigerant leaving the evaporator is monitored and analysed, as described above. In the case that the analysis reveals that an absolute value of a rate of change of the temperature signal, S_2 , has reached a maximum value, the opening degree of the expansion valve is decreased.

- 15 As described above, an abrupt decrease in the rate of change of the monitored temperature signal, S_2 , indicates that the unstable region has been entered, and that the dry zone of the evaporator is therefore approaching a minimum length. Accordingly, this indicates that there is a risk that liquid refrigerant is allowed to pass through the evaporator if the maximum opening degree of the expansion valve is maintained, and therefore the opening degree of
- 20 the expansion valve must be decreased in order to avoid this situation.

Thus, according to this embodiment, an efficient pull down process is provided, while it is ensured that liquid refrigerant is not allowed to reach the compressor.

- According to a second aspect the invention provides a method for controlling a supply of refrigerant to an evaporator of a vapour compression system during a pull down process, the
- 25 vapour compression system comprising at least one evaporator, at least one compressor, at least one condenser and at least one expansion valve arranged in a refrigerant circuit, the method comprising the steps of:

- opening the expansion valve to a maximum opening degree,

- monitoring a temperature signal, S_2 , representing a temperature of refrigerant leaving the evaporator,
- analysing the temperature signal, S_2 , and
- decreasing the opening degree of the expansion valve in the case that said analysis reveals that an absolute value of a rate of change of the temperature signal, S_2 , reaches a maximum value.

It should be noted that a person skilled in the art would readily recognise that any feature described in combination with the first aspect of the invention could also be combined with the second aspect of the invention, and vice versa. Thus, the remarks set forth above are equally applicable here.

The pull down process of the second aspect of the invention has already been described in detail above.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in further detail with reference to the accompanying drawings in which

Fig. 1 is a graph illustrating a monitored temperature, S_2 , as a function of opening degree of an expansion valve,

Fig. 2 is a diagrammatic view of a part of a vapour compression system for performing a method according to a first embodiment of the invention,

Fig. 3 is a diagrammatic view of a part of a vapour compression system for performing a method according to a second embodiment of the invention, and

Fig. 4 is graph illustrating opening degree of an expansion valve and monitored temperatures of a vapour compression system, while performing a method according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graph illustrating a monitored temperature, S_2 , of refrigerant leaving an evaporator of a vapour compression system, as a function of opening degree of an expansion valve which controls the supply of refrigerant to the evaporator.

- 5 It can be seen that when the opening degree of the expansion valve is relatively small, the monitored temperature, S_2 , of the refrigerant leaving the evaporator is relatively high, close to a temperature, T_{air} , of ambient air. Furthermore, the monitored temperature, S_2 , remains almost constant when the opening degree of the expansion valve is increased. This indicates that the liquid part of the refrigerant, which is supplied to the evaporator, is evaporated well
10 before it reaches the outlet of the evaporator. Accordingly, the superheat value of the refrigerant leaving the evaporator can be assumed to be relatively high, and the risk of liquid refrigerant passing through the evaporator is very low.

- As the opening degree of the expansion valve is increased further, the monitored temperature, S_2 , decreases significantly and abruptly towards an evaporating temperature,
15 T_e , i.e. the temperature at which the refrigerant evaporates at the pressure prevailing in the refrigerant, or the dew point. Thus, when the monitored temperature, S_2 , approaches the evaporating temperature, T_e , this is an indication that the superheat value is approaching zero. This is an indication that the dry zone of the evaporator is approaching a minimum length, and that the risk of liquid refrigerant passing through the evaporator is increasing.

- 20 The region where the monitored temperature, S_2 , decreases abruptly may be referred to as an 'unstable region'. When monitoring and analysing the temperature, S_2 , entering this region can be detected, e.g. by monitoring the rate of change of the temperature signal, and identifying an absolute maximum value of the rate of change, since the rate of change will be large and negative. However, entering the unstable region may be detected in other ways, as
25 described above.

- The region where the rate of change of the monitored temperature, S_2 , once again decreases, and the temperature, S_2 , comes very close to the evaporating temperature, may be referred to as a 'critical region', because this is the region where there is a high risk that liquid
30 refrigerant is allowed to pass through the evaporator, and thereby there is a risk that liquid refrigerant may reach the compressor.

Thus, it is desirable to control the opening degree of the expansion valve in such a manner that the critical region is not entered. According to the present invention, this may be obtained by reducing the opening degree of the expansion valve when it is detected that the

unstable region is entered. When this occurs, the critical region will be reached if the opening degree of the expansion valve is increased further. Therefore it can be prevented that the critical region is entered, if the opening degree of the expansion valve is reduced when the unstable region is entered.

- 5 It is noted that since the evaporating temperature, T_e , depends on the pressure prevailing in the refrigerant, it will normally not be sufficient to measure the temperature, S_2 , of refrigerant leaving the evaporator, and compare the measured temperature to a fixed evaporating temperature. This is why, in the method of the present invention, the temperature signal, S_2 , is monitored and analysed, e.g. deriving the rate of change of the
10 temperature signal, in order to detect when the unstable region is entered.

Fig. 2 is a diagrammatic view of a part of a vapour compression system 1 for performing a method according to a first embodiment of the invention. The vapour compression system 1 comprises an evaporator 2 arranged in a refrigerant circuit along with one or more compressors (not shown) and one or more condensers (not shown). An expansion valve 3 is
15 also arranged in the refrigerant circuit for controlling the supply of refrigerant to the evaporator 2.

The vapour compression system 1 further comprises a number of temperature sensors. A first temperature sensor 4 is arranged in the refrigerant circuit after the outlet of the evaporator 2. Accordingly, the first temperature sensor 4 measures a temperature signal, S_2 ,
20 which represents the temperature of refrigerant leaving the evaporator 2.

A second temperature sensor 5 is arranged in a secondary air flow across the evaporator 2, at a position before the air reaches the evaporator 2. Accordingly, the second temperature sensor 5 measures a temperature signal, S_3 , which represents the temperature of air flowing towards the evaporator 2.

25 A third temperature sensor 6 is arranged in the secondary air flow across the evaporator 2, at a position after the air has passed the evaporator 2. Accordingly, the third temperature sensor 6 measures a temperature signal, S_4 , which represents the temperature of air flowing away from the evaporator 2.

The temperature signals, S_3 and S_4 , measured by the second temperature sensor 5 and the
30 third temperature sensor 6 are supplied to a sensor selection unit 7. The sensor selection unit 7 selects whether to apply one of the temperature signals, S_3 and S_4 , when controlling the expansion valve 3, or to apply a weighted value of the two temperature signals, S_3 and S_4 . The selection may, e.g., be based on the availability of sensors 5 and 6, or on the choice of

the installer. Based on the selection, a temperature signal, T_{air} , is generated, and T_{air} represents an air temperature, corresponding to the selection performed by the selection unit 7. The temperature signal, T_{air} , is supplied to a control unit 8, which is arranged to control an opening degree of the expansion valve 3.

- 5 A reference air temperature, $T_{air, ref}$, is also supplied to the control unit 8. The reference air temperature, $T_{air, ref}$, represents a reference or target temperature which is desired in the air flowing across the evaporator 2.

The control unit 8 compares the temperature signal, T_{air} , to the reference air temperature, $T_{air, ref}$, and calculates an opening degree of the expansion valve 3, based on this comparison.

- 10 The opening degree of the expansion valve 3 is selected in such a manner that the opening degree ensures a supply of refrigerant to the evaporator 2, which causes the air temperature, T_{air} , to approach the reference air temperature, $T_{air, ref}$. Thus, the control unit 8 controls the opening degree of the expansion valve 3 on the basis of the selected air temperature, T_{air} , and in order to reach the reference air temperature, $T_{air, ref}$.

- 15 The temperature signal, S_2 , measured by the first temperature sensor 4 is also supplied to the control unit 8. Thereby, the temperature of refrigerant leaving the evaporator 2 may also be taken into account when the opening degree of the expansion valve 3 is calculated by the control unit 8.

- 20 When the control unit 8 has calculated an opening degree of the expansion valve 3 as described above, the control unit 8 applies a perturbation signal to the calculated opening degree. In the embodiment illustrated in Fig. 2, the perturbation signal is a relay like perturbation signal. The resulting signal is supplied to the expansion valve 3, and the opening degree of the expansion valve 3 is controlled to be the calculated opening degree, overlaid with the perturbation signal.

- 25 Thus, under normal circumstances, the opening degree of the expansion valve 3, and thereby the supply of refrigerant to the evaporator 2, is controlled on the basis of the air temperature, T_{air} , in order to obtain the reference air temperature, $T_{air, ref}$, but overlaid with the perturbation signal.

- 30 However, the temperature signal, S_2 , measured by the first temperature sensor 4, is also supplied to an analysing unit 9. The analysing unit 9 analyses the temperature signal, S_2 , in particular with respect to the rate of change of the temperature signal, S_2 . The result of the analysis is supplied to a safety logic unit 10. The safety logic unit 10 monitors the rate of change of the temperature signal, S_2 , and in the case that an absolute value of the rate of

change of the temperature signal, S_{2r} , reaches a maximum value, the safety logic unit 10 sends a signal to the control unit 8, requesting that the opening degree of the expansion valve 3 is decreased. In response to this signal, the control unit 8 decreases the opening degree of the expansion valve 3.

- 5 As described above, when the rate of change of the temperature of refrigerant leaving the evaporator 2, decreases abruptly, this is a sign that the unstable region has been entered, and that there is a risk of entering the critical region, if the opening degree of the expansion valve 3 is not decreased. Therefore, the safety logic unit 10 in this manner ensures that it is efficiently prevented that liquid refrigerant is allowed to pass through the evaporator 2 and reach the compressor.

Fig. 3 is a diagrammatic view of a part of a vapour compression system 1 for performing a method according to a second embodiment of the invention. The vapour compression system 1 of Fig. 3 operates in a manner which is similar to the operation of the vapour compression system of Fig. 2, and the operation of the vapour compression system 1 will therefore not be described in detail here.

The vapour compression system 1 of Fig. 3 further comprises a first bandpass filter 11, through which the selected temperature signal, T_{airr} , is passed, along with the reference air temperature, $T_{air, ref}$, to a control unit 12. The control unit 12 could, e.g. be a proportional integral (PI) regulator. The output of the control unit 12 is supplied to a summation unit 13.

- 20 The vapour compression system 1 of Fig. 3 also comprises a second bandpass filter 14, through which the temperature signal, S_{2r} , measured by the first temperature sensor 4 is passed before being supplied to the summation unit 13.

The summation unit 13 is further provided with a reference temperature signal, $S_{2, ref}$, representing a target or reference temperature for refrigerant leaving the evaporator 2.

- 25 Passing the temperature signals, T_{air} and S_{2r} , through bandpass filters 11 and 14 ensures that only temperature signals within a desired frequency band are applied for controlling the opening degree of the expansion valve 3. It should be noted that the bandpass filters 11 and 14 could conveniently be realized in the control units 12 and 8.

Based on the signals supplied thereto, the summation unit 13 provides an input signal to the control unit 8. The input signal reflects the comparison between the selected air temperature, T_{airr} , and the reference air temperature, $T_{air, ref}$, provided by the control unit 12, as well as a

comparison between the measured temperature signal, $S_{2,}$ and the reference temperature, $S_{2, \text{ref}}$, which is performed by the summation unit 13.

Based on the input signal, the control unit 8 calculates an opening degree of the expansion valve 3, essentially as described above. The calculated opening degree is supplied to a summation unit 15. A perturbation unit 16 generates a perturbation signal and supplies this to the summation unit 15. The summation unit 15 then defines an opening degree of the expansion valve 3 as the calculated opening degree overlaid with the perturbation signal. In the embodiment of Fig. 3, the perturbation signal is a sinusoidal signal.

The safety mechanism provided by the analysing unit 9 and the safety logic unit 10 operates essentially as described above with reference to Fig. 2, except that it may apply alternative ways of detecting that the unstable region has been entered. Such alternative ways have already been described above.

Fig. 4 is graph illustrating opening degree of an expansion valve and monitored temperatures of a vapour compression system, while performing a method according to an embodiment of the invention. The vapour compression system could, e.g., be the vapour compression system of Fig. 2 or the vapour compression system of Fig. 3.

The graph of Fig. 4 illustrates how the opening degree 17 varies as a function of time, and how various temperatures measured in the vapour compression system react to the variations of the opening degree 17. It should be noted, that in Fig. 4 the opening degree 17 is shown without the overlaid perturbation signal for clarity. Graph 18 represents the temperature of refrigerant leaving the evaporator, i.e. corresponding to the temperature signal, $S_{2,}$ described above. Graph 19 represents the temperature of air flowing towards the evaporator, i.e. corresponding to the temperature signal, $S_{3,}$ described above. Graph 20 represents the temperature of air flowing away from the evaporator, i.e. corresponding to the temperature signal, $S_{4,}$ described above. Graph 21 represents the evaporating temperature, i.e. the temperature at which the refrigerant evaporates in the evaporator. This temperature varies in dependence of the pressure prevailing in the refrigerant. Finally, graph 22 represents the reference air temperature, $T_{\text{air, ref}}$.

It can be seen from Fig. 4, that initially the temperatures 18, 19 and 20 are all relatively high. In particular, the air temperatures 19, 20 are both significantly higher than the reference air temperature 22, and the temperature 18 of refrigerant leaving the evaporator is significantly higher than the evaporating temperature 21. This is due to the fact that the vapour compression system has recently been switched on after having been switched off for a period of time, and indicates that a large cooling effect is required in order to reach the

reference air temperature 22. Furthermore, the superheat value of refrigerant leaving the evaporator is relatively high, and therefore the risk of liquid refrigerant passing through the evaporator is very low.

5 As a consequence, a pull down process is initiated. This includes opening the expansion valve to a maximum opening degree, while monitoring the various temperature signals 18, 19, 20. It is clear from Fig. 4, that this causes the measured air temperatures 19, 20 to decrease rapidly. Furthermore, the temperature 18 of refrigerant leaving the evaporator decreases and approaches the evaporating temperature 21, i.e. the superheat value of the refrigerant leaving the evaporator decreases towards zero.

10 After a while, an absolute value of the rate of change of the temperature 18 of refrigerant leaving the evaporator reaches a maximum value. This can be seen in Fig. 4 as an abrupt decrease in the temperature 18. As described above, this is an indication that the unstable region has been entered, and therefore, in response thereto, the opening degree 17 of the expansion valve is decreased to a minimum value. Thereby the pull down process is
15 terminated, and a system identification period is entered. It is clear from Fig. 4, that the temperature 18 is indeed approaching the evaporating temperature 21, at the time where the opening degree 17 is decreased to the minimum value.

During the system identification period, the opening degree 17 of the expansion valve is switched between the maximum value and the minimum value, while the temperatures 18,
20 19, 20 are monitored. It can be seen, that each time the temperature 18 of refrigerant leaving the evaporator decreases abruptly, in the manner described above, the opening degree 17 is switched from the maximum value to the minimum value. One of the objectives of the system identification period is to identify the current operating point of the system.

After a while the system identification period is terminated, and a normal control period is
25 initiated. During the normal control period, the opening degree 17 of the expansion valve is controlled on the basis of the temperature 20 of air flowing away from the evaporator, and in order to reach the reference temperature 22. However, a safety process is also applied, which ensures that the opening degree 17 of the expansion valve is decreased to the minimum value in the case that it is detected that the unstable region has been entered, e.g.
30 by means of an analysis of the rate of change of the temperature signal 18. In the situation illustrated in Fig. 4, the temperature 18 of refrigerant leaving the evaporator stays well above the evaporating temperature 21 during the entire normal control period. Thus, the unstable region is not entered, there is no risk of liquid refrigerant passing through the evaporator, and the safety process is therefore not applied.

CLAIMS

1. A method for controlling a supply of refrigerant to an evaporator (2) of a vapour compression system (1), the vapour compression system (1) comprising at least one evaporator (2), at least one compressor, at least one condenser and at least one expansion valve (3) arranged in a refrigerant circuit, the method comprising the steps of:
 - 5 – obtaining a temperature, T_{air} , of air flowing across the evaporator (2),
 - controlling an opening degree of the expansion valve (3), on the basis of the obtained temperature, T_{air} , and in order to reach a reference air temperature, $T_{air, ref}$, of the air flowing across the evaporator (2),
 - 10 – providing a perturbation signal, and setting the opening degree of the expansion valve (3) to the controlled opening degree, overlaid with the perturbation signal,
 - monitoring a temperature signal, S_2 , representing a temperature of refrigerant leaving the evaporator (2),
 - analysing the temperature signal, S_2 , and
 - 15 – decreasing the opening degree of the expansion valve (3) in the case that said analysis reveals that a dry zone of the evaporator (2) is approaching a minimum length.
2. A method according to claim 1, wherein the step of analysing the temperature signal, S_2 , comprises obtaining a rate of change of the temperature signal, S_2 , and wherein the step of
 - 20 decreasing the opening degree comprises decreasing the opening degree of the expansion valve (3) in the case that an absolute value of the rate of change of the temperature signal, S_2 , reaches a maximum value.
3. A method according to claim 1, wherein the step of analysing the temperature signal, S_2 , comprises the steps of:
 - 25 – identifying a component of the temperature signal, S_2 , corresponding to the perturbation signal,

- comparing the identified component of the temperature signal, S_2 , to the original perturbation signal, and
 - determining whether or not the dry zone of the evaporator (2) is approaching a minimum length, based on said comparison.
- 5 4. A method according to claim 3, wherein the step of comparing comprises determining a distortion of the identified component of the temperature signal, S_2 .
5. A method according to claim 1, wherein the step of analysing the temperature signal, S_2 , comprises identifying one or more statistical components of the temperature signal, S_2 .
6. A method according to any of the preceding claims, wherein the perturbation signal is a
10 sinusoidal type signal.
7. A method according to any of claims 1-5, wherein the perturbation signal is a relay type signal.
8. A method according to any of the preceding claims, wherein the temperature, T_{air} , is a temperature of air flowing towards the evaporator (2).
- 15 9. A method according to any of claims 1-7, wherein the temperature, T_{air} , is a temperature of air flowing away from the evaporator (2).
10. A method according to any of claims 1-7, wherein the temperature, T_{air} , represents a weighted value of a temperature of air flowing towards the evaporator (2) and a temperature of air flowing away from the evaporator (2).
- 20 11. A method according to any of the preceding claims, further comprising the step of performing a pull down process in the case that the temperature, T_{air} , of air flowing across the evaporator (2) is above a predefined upper threshold value.
12. A method according to claim 11, wherein the step of performing a pull down process comprises the steps of:
- 25 – opening the expansion valve (3) to a maximum opening degree,

- monitoring a temperature signal, S_2 , representing a temperature of refrigerant leaving the evaporator (2),
- analysing the temperature signal, S_2 , and
- decreasing the opening degree of the expansion valve (3) in the case that said analysis reveals that an absolute value of a rate of change of the temperature signal, S_2 , has reached a maximum value.

13. A method for controlling a supply of refrigerant to an evaporator (2) of a vapour compression system (1) during a pull down process, the vapour compression system (1) comprising at least one evaporator (2), at least one compressor, at least one condenser and at least one expansion valve (3) arranged in a refrigerant circuit, the method comprising the steps of:

- opening the expansion valve (3) to a maximum opening degree,
- monitoring a temperature signal, S_2 , representing a temperature of refrigerant leaving the evaporator (2),
- analysing the temperature signal, S_2 , and
- decreasing the opening degree of the expansion valve (3) in the case that said analysis reveals that an absolute value of a rate of change of the temperature signal, S_2 , reaches a maximum value.

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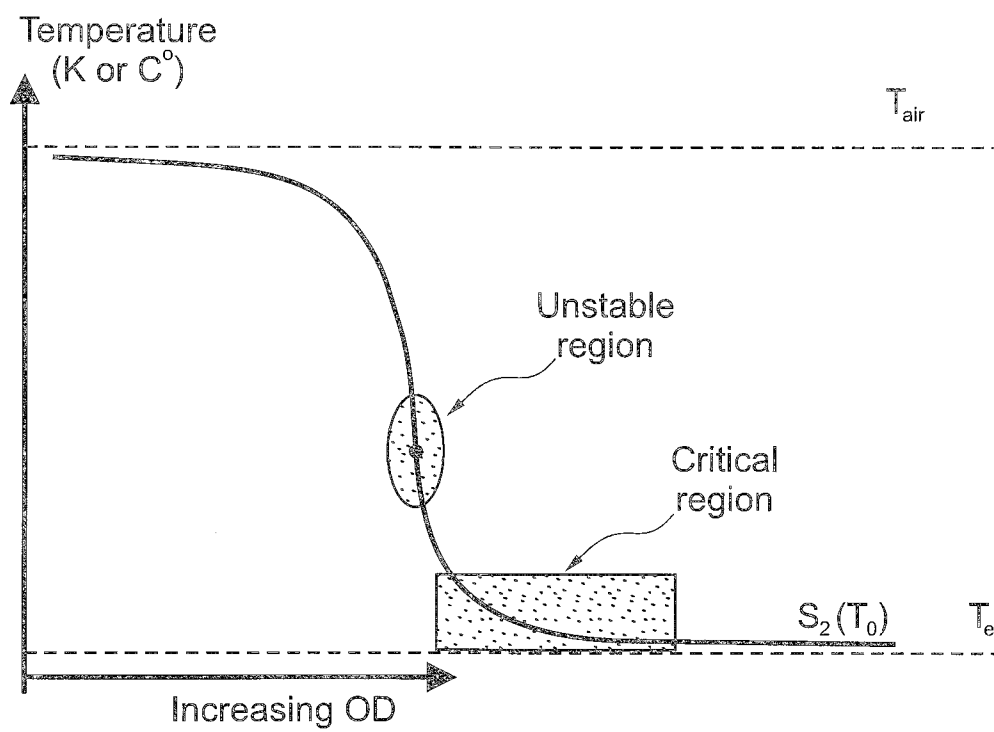


Fig. 1

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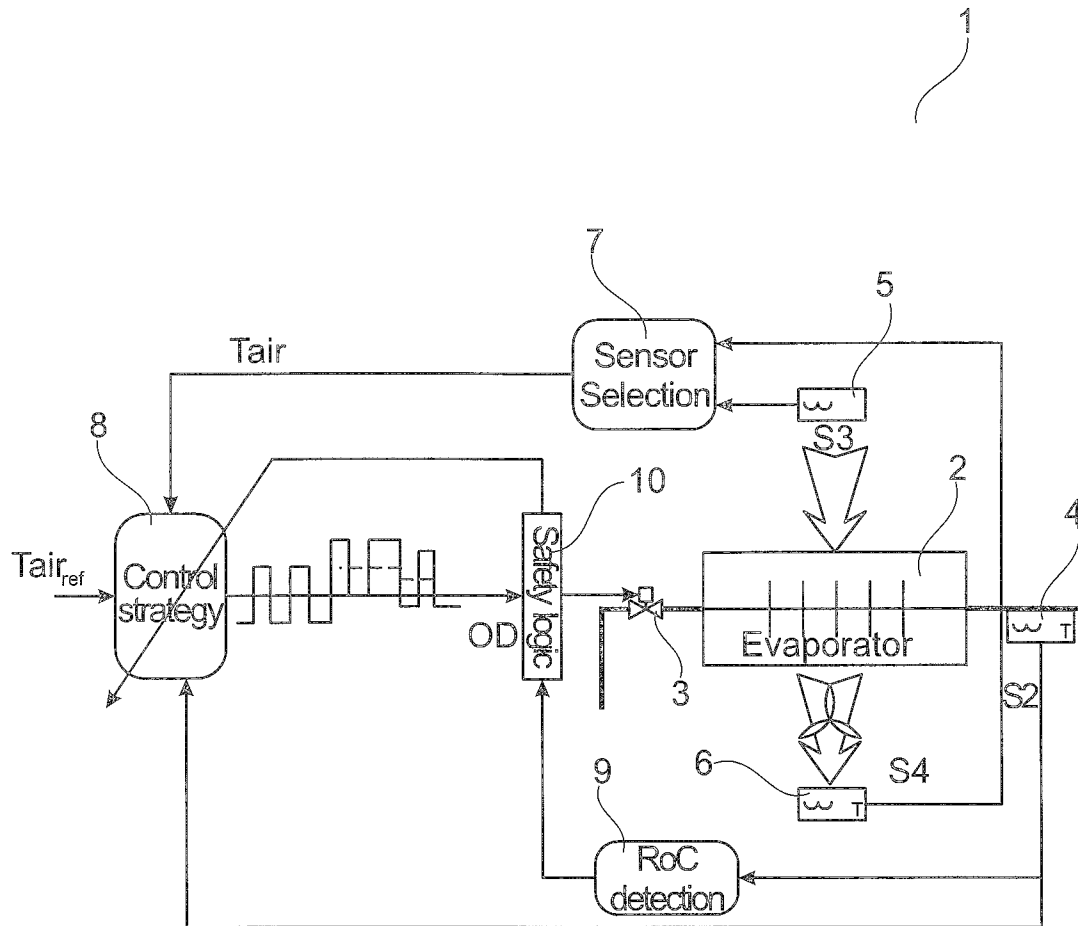


Fig. 2

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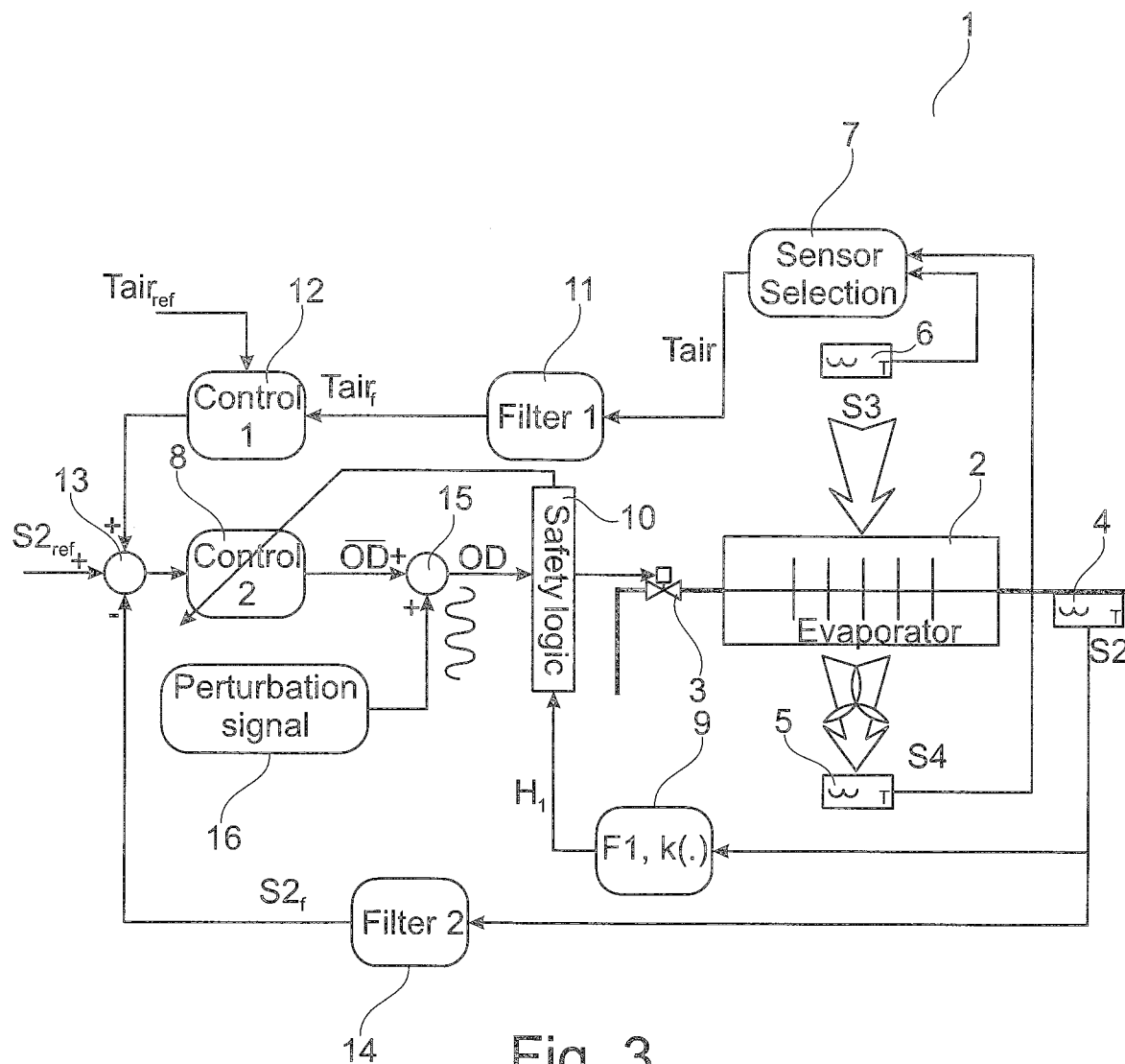


Fig. 3

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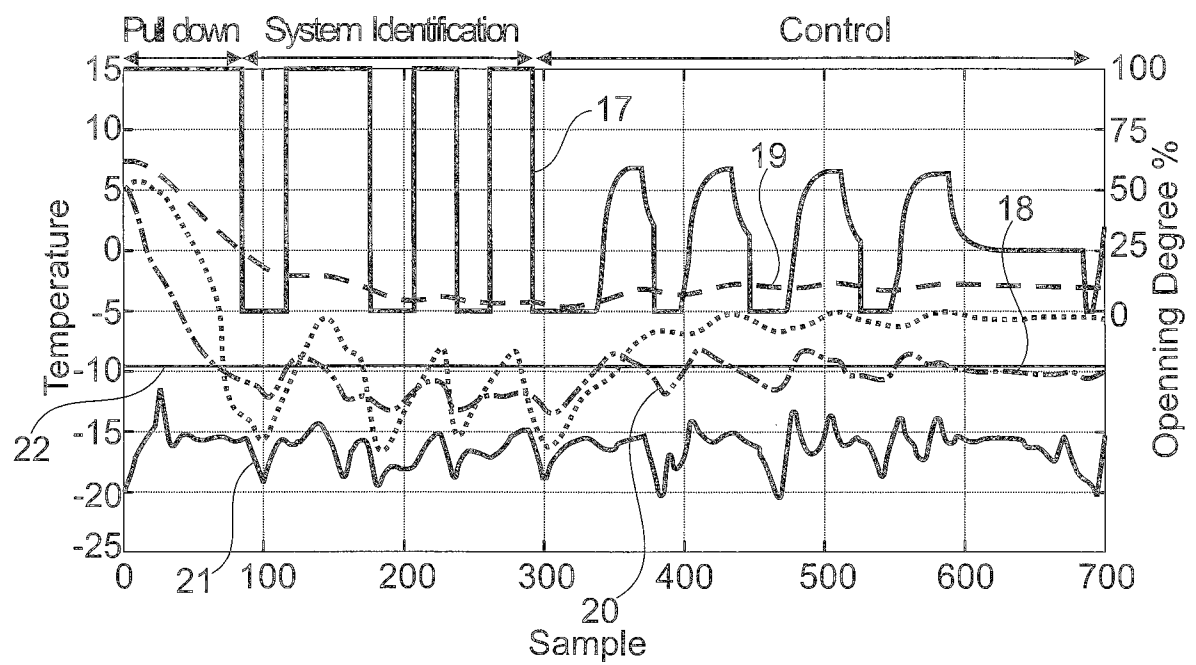


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2014/077904

A. CLASSIFICATION OF SUBJECT MATTER
INV. F25B49/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 41 00 749 A1 (DANFOSS AS [DK]) 16 July 1992 (1992-07-16)	1,3-11
Y	the whole document	2,12,13
Y	US 2007/175229 A1 (REDLICH ROBERT W [US]) 2 August 2007 (2007-08-02)	2,12,13
Y	the whole document	
A	US 2011/214438 A1 (LARSEN LARS FINN SLOTH [DK] ET AL) 8 September 2011 (2011-09-08)	1-13
A	the whole document	
A	US 2013/205815 A1 (IZADI-ZAMANABADI ROOZBEH [DK] ET AL) 15 August 2013 (2013-08-15)	1-13
A	the whole document	



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

16 February 2015

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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