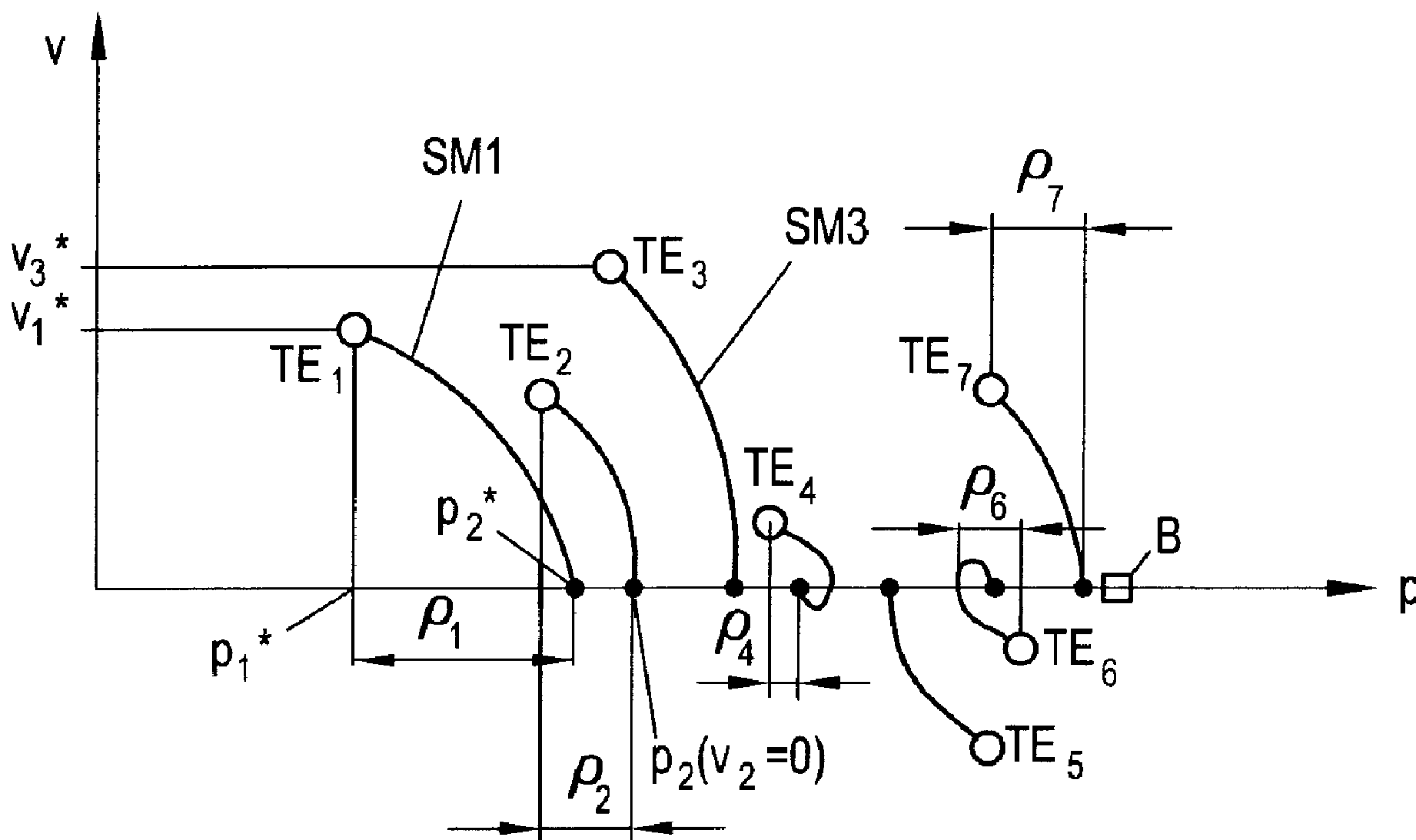




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(54) Titre : METHODE D'UTILISATION D'UN DISPOSITIF DE TRANSPORT AYANT LA FORME D'UN MOTEUR LINEAIRE A STATOR LINEAIRE
(54) Title: METHOD FOR OPERATING A TRANSPORT ASSEMBLY IN THE FORM OF A LINEAR STATOR LINEAR MOTOR



(57) Abrégé/Abstract:

In order to avoid a collision between transport units, which are moving along a transport path of a transport assembly, and/or the collision of a transport unit with a barrier and/or the surpassing of a local speed limit, for at least one transport unit (TE_i) it is

(57) **Abrégé(suite)/Abstract(continued):**

preemptively determined if for the transport unit (TEi) a stopping maneuver (SMi) with a predetermined cinematic may be performed, without causing a violation of these safety requirements. In case of violation of a safety requirement, the stopping maneuver is effectively activated.

Abstract

In order to avoid a collision between transport units, which are moving along a transport path of a transport assembly, and/or the collision of a transport unit with a barrier and/or the surpassing of a local speed limit, for at least one transport unit (TE_i) it is preemptively determined if for the transport unit (TE_i) a stopping maneuver (SM_i) with a predetermined cinematic may be performed, without causing a violation of these safety requirements. In case of violation of a safety requirement, the stopping maneuver is effectively activated.

Method for operating a transport assembly in the form of a linear stator linear motor

The present invention refers to a method for operating a transport assembly in the form of a long stator linear motor through which a plurality of transport units are moved along a transport path, wherein the movement of the transport units along the transport path is adjusted by setting setpoints of movement by at least one transport unit control.

Long stator linear motors are often used as flexible transport assemblies in production plants, machining plants, assembling plants and similar plants. A long stator linear motor is notoriously essentially composed of a long stator formed by a plurality of successively positioned driving coils and a plurality of transport units with excitation magnets (permanent magnets or electro-magnets), which are moved along the long stator by energizing the respective driving coils with an electric current. The driving coils generate a moving magnetic field, which interacts with the excitation magnets on the transport units, in order to move the transport units. The long stator therefore forms a transport path, along which the transport units may be moved. Therefore it is possible to control the movement (position, velocity, acceleration) of each transport unit individually and independently from one another. To this end, each driving coil is controlled by an associated driving coil controller, which can obtain settings for moving a transport unit (for instance in the form of setpoints for position or velocity) from a superordinate plant control unit. Switches for the long stator linear motor may be provided along the transport path. The long stator is often formed by transport segments, wherein each transport segment forms a portion of the transport path and contains a number of driving coils. Usually a segment control is provided for a transport segment, which controls all driving coils of the transport segment. The design of the long stator linear motor, i.e. for instance the design of the driving coils, the transport path, the transport units, the guides of the transport unit, etc., and the control principle may obviously vary, wherein however the basic operating principle of a long stator linear motor remains the same.

A transport assembly provided in the form of a long stator linear motor may become complex, with a plurality of transport segments, which may also be connected to each other by means of switches. A great number of transport units may also be simultaneously moved on the same. Such a transport assembly therefore imposes high requirements on the control of the movement of individual transport units. In particular, normally, provisions have to be taken in order to avoid that single transport units do not collide during their movement.

US 8,863,669 B2 describes a transport assembly, for example, which is formed by a long stator linear motor with a control of movement of transport units. The transport path is divided into zones, wherein a transport unit is controlled in a setpoint based zone based on a setpoint set-

ting, and in a limit value based zone by means of settings for end position and maximum values of velocity and acceleration. In the limit value based control, these settings are transformed into a movement profile, according to which the transport unit is moved. US 8,863,669 B2 also indicates that collisions of transport units have to be avoided, wherein no indication is provided on
5 how this control is achieved.

In the same way, along the transport path barriers may be provided, which cannot be overridden by a transport unit. Such barriers may be real, physical barriers, such as, for example, the end of a transport segment, or logical barriers, for instance a switch, which is simultaneously occupied by another transport unit, or a transport segment in which there is no space for a further transport unit. Barriers may also be imposed, according to application, even temporarily, by
10 the higher level plant control unit. Also barriers may not be overridden by the transport units during operation.

Not least, along the transport path local speed limits may be imposed, which may not be violated by a transport unit, for example a maximum speed in a curve, in order to avoid exceeding a
15 maximum allowable centrifugal force.

It is an object of the present invention to provide a method, through which a collision between transport units, which are moving along a transport path of a long stator linear motor, and/or the collision of a transport unit with a barrier and/or exceeding of a local speed limit may be avoided.

This object is achieved in that for at least one first transport unit it is preemptively determined, if
20 for the transport unit a stopping maneuver with a predetermined cinematic may be performed with a predetermined cinematic, so that a collision of this transport unit with a preceding second transport unit or with a barrier of the transport path (2) is avoided, or exceeding of a predetermined local speed limitation in a position of the transport path by the first transport unit is avoided,
25 or a matching movement of the first transport unit to a speed of a preceding second transport unit is possible, and in that the stopping maneuver of the first transport unit is effectively activated, when at least one of these conditions is violated. Due to the predictive calculation of stopping maneuvers and the simultaneous verification of violation of security requirements, it is possible to ensure that a transport unit may be stopped, without conflicting with another transport unit, a barrier, or a speed limit. If the risk of violation of a security requirement is
30 impending, the transport unit is effectively stopped.

In a preferred embodiment, a stopping maneuver is deduced for the preceding second transport unit and it is checked, if the first transport unit in case of a presumed stopping maneuver, gets too close to the second transport unit. In the normal case, the stopping maneuver is activated
35 as fast as possible. If a collision, during a stopping maneuver of the second preceding transport

unit can be avoided, it is therefore possible to assume that during normal driving maneuvers, a collision may also be avoided.

In a simple embodiment, for the first transport unit and for the second transport unit, on the basis of the knowledge of the cinematic implementation of the respective stopping maneuver, a
 5 respective stopping point or a stopping distance are calculated and these are compared, in order to determine if the first and second transport units get too close to each other.

In order to consider fixed barriers, it may be checked, if the first transport unit, in case of a presumed stopping maneuver, gets too close to the barrier. It is therefore ensured that a transport unit may always be timely stopped before a barrier.

10 The safety may be increased if a minimum distance is set, which indicates how close the transport unit may get to the preceding transport unit or barrier.

The compliance with a speed limit may be easily checked, if it is checked that the speed of the first transport unit during a presumed stopping maneuver may be reduced from a current actual speed to a predetermined limited speed, imposed by the speed limit, without the first transport
 15 unit getting too close to the defined area of speed limitation. It is therefore ensured that a transport unit may always be decelerated to a defined speed, without any violation of the speed limit. In a simple implementation, for the first transport unit, based on the knowledge of the cinematic implementation of the stopping maneuver, a speed point or braking distance is calculated, and therefore it is determined if the speed of the transport unit may be reduced to the limit
 20 speed before reaching the area of speed limitation.

A collision may be avoided through a matching maneuver, if it is checked, if the speed of the first transport unit in case of a presumed stopping maneuver, may be reduced from the current actual speed to a speed of the second transport unit, so that between the first and second transport unit a safety distance is maintained, which is obtained by the concrete cinematic im-
 25 plementation of the stopping maneuver. It is therefore ensured that the speed of the first transport unit may always be reduced to the speed of the second transport unit, without a collision. In a simple implementation, for the first transport unit, based on the knowledge of the cinematic implementation of the stopping maneuver, a speed point or compensation distance is calculated and it is determined if the speed of the transport unit may be reduced to the speed of
 30 the second transport unit.

The present invention is described in detail in the following with reference to figures 1 to 8, which schematically and illustratively show, in a non-limiting way, advantageous embodiments of the invention. In particular:

Fig.1 shows an example of a transport assembly,

35 Fig. 2 shows an example of a collision avoidance through stopping maneuver according to the

invention,

Fig. 3 shows an example of the compliance with a speed limit according to the invention,

Fig.4 shows an example of a matching movement according to the invention,

Fig.5 shows the compliance with a speed limit through a matching movement,

5 Figs.6 and 7 show the management of switches during monitoring of safety settings and

Fig.8 shows the implementation of a transport unit control with a phase space limitation.

Fig. 1 shows an example of a design of a transport assembly 1 with a transport path 2 (indicated by the dashed line). The transport assembly 1 is implemented as long stator linear motor and a plurality of transport units TE_i , $i = 1, \dots, x$ are provided, which may be moved along the

10 transport path 2. The transport path 2 is defined given by the long stator of the long stator linear motor 1. In the exemplary embodiment shown, a series of transport segments FS_i , $i = 1, \dots, y$ is provided, which define the path of the transport units TE_i , i.e. the transport path 2. Individual transport portions FA_i , $i = 1, \dots, z$ of the transport path 2 are formed by a number of adjacent transport segments FS_i . The transport segments FS_i , and therefore also the transport portions

15 FA_i , form a part of the long stator of the long stator linear motor. The transport segments FS_i are fixed in a suitable construction and normally also provided guiding elements, along which the transport units TE_i may be guided. Each transport portion FA_i comprises at least one transport segment FS_i , normally a plurality of transport segments FS_i . Individual transport portions FA_i , or transport segments FS_i of individual transport portions FA_i (as for example the transport segments FS_1 , FS_m), may also partially overlap along the transport path 2, in particular at points of the transport path 2, in which the transition from a transport portion FA_i to another transport portion FA_i takes place (as for example from transport portion FA_1 to transport portion FA_2). It may also be provided that in sections on both sides of the transport path 2 transport segments are arranged. Switches W may also be provided, at which (according to the transport direction of a

25 transport unit TE_i) two transport portions FA_i converge or a splitting on two transport portions FA_i is provided. It is understandable that in this way an almost arbitrarily structured transport path 2 may be formed, which has not to be in a two-dimensional plane, but may also extend in three dimensions.

Each transport segment FS_i comprises a number k of driving coils AS_{ij} , $j = 1, \dots, k$, wherein the

30 number k need not to be the same for each transport segment FS_i . In Fig. 1, for clearness, only driving coils AS_{ij} of some transport segments FS_i are shown. Each transport unit TE_i comprises a number of excitation magnets EM_{ij} , $j = 1, \dots, l$, preferably on both sides (with respect to the transport direction, which is indicated by arrows on the transport units TE_i) of the transport unit TE_i . The driving coils AS_{ij} generate a moving magnetic field and interact in operation of

35 transport assembly 1 in a known way according to the motor principle with the excitation magnets EM_{ij} of the transport units TE_i . If the driving coils AS_{ij} are electrically energized with a coil current in the area of a transport unit TE_i , a magnetic flux is formed, which, by interacting with

the excitation magnets EM_{ij} , creates a force on the transport unit TE_i . This force may, according to the coil current, comprise, in a known way, a force component forming a thrust force and a component forming a lateral force. The thrust force component essentially provided movement of the transport unit TE_i and the lateral force component may be used for guiding the transport unit TE_i , but also for defining the path of the transport unit TE_i in a switch W . In this way, each transport unit TE_i may be moved individually and independently from each other along the transport path 2, in that the driving coils AS_{ij} are energized in the area of each transport unit TE_i with a corresponding coil current according to the movement to be performed.

This fundamental functional principle of a long stator linear motor is sufficiently known, so that it is not described in further detail. For the present invention it is also irrelevant how the transport units TE_i , the transport segments FS_i , the driving coils AS_{ij} , the excitation magnets EM_{ij} , etc., are concretely design, whereby their detailed description is also omitted.

In order to control the individual transport units TE_i a transport unit control 3 is provided, in which the setpoints S for the movement of transport units TE_i are generated. Obviously a plurality of transport unit controls 3 may also be provided, which are associated to a part of the transport assembly 1, for instance to a transport portion FA_i , respectively, and control the movement of the transport units TE_i on this part. Additionally, segment control units 4 may also be provided, which are associated to a transport segment FS_i (or even a plurality of transport segments FS_i or a part of a transport segments FS_i) and convert the setpoint settings of the corresponding transport unit control 3 for a transport unit TE_i into coil currents for driving coils AS_{ij} of transport segments FS_i , into concrete values of control variables. The segment control units 4 may however also be implemented in a transport unit control 3. The setpoints S are set as positions p of transport units TE_i , or, equally, speeds v . This means that in each cycle step n of control for each transport unit TE_i a new setpoint S is calculated, which is adjusted by the segment control units 4. In a segment control unit 4, a suitable controller is implemented, which converts the setpoint settings in a suitable control variable, for instance in a force or coil current. The desired movement of the transport units TE_i along the transport path 2 may also be set by a transport assembly control 5, which for example performs a routing calculation (for example which path should a transport unit TE_i follow?), a switch arbitration (for example which transport unit TE_i may enter a switch?), a deadlock avoidance (for example, are two transport units TE_i blocking each other?), etc., in order to move the transport units TE_i in a desired way along the transport path 2, for example in order to execute production, assembly or other processes. These movement settings for the transport units TE_i are converted in the transport units control 3 into setpoint settings for the transport units TE_i .

In principle, in the transport assembly control 5 it should be ensured, that on the transport path 2, no inadmissible condition takes place. This comprises primarily the avoidance of collisions

between two transport units TE_i on the transport path 2. In the same way, it should be ensured that transport units TE_i do not uncontrollably overpass barriers, for example uncontrollably enter switches W or a transport segment FS_i , which can also lead to a collision. Moreover, the compliance with speed limits for transport units TE_i may be ensured. The compliance with these safety settings (in particular the collision avoidance, but also the compliance with speed limits) is important for an undisturbed operation of the transport assembly 1.

During operation of transport assembly 1, in particular in case of large transport assemblies 1 with a high number of transport units TE_i and many transport portions FA_i , it may nonetheless happen, that above said safety settings are violated. In order to be able to prevent these faults in such a case, it is provided, according to the invention, that in the setpoint generation in the transport unit control 3 in each cycle step n it is verified, that no collision between two transport units TE_i may take place. Additionally, for each transport unit TE_i the compliance with preset speed limits may also be checked. If a collision risk and/or the risk of speed surpassing is recognized, the transport unit control 3 activates a corresponding action. The basic idea to this end is always that at any time it has to be possible to stop a transport unit TE_i , without the transport unit TE_i colliding with another transport unit TE_i , wherein also during the stopping process, i.e. during deceleration, a collision must not take place. According to the invention it is presumed that a transport unit TE_i always monitors the movement of preceding (according to the transport direction of transport unit TE_i) transport units TE_k , $k > i$, with which a collision may take place, in order to monitor the compliance with the safety settings. In the simplest case, this is the immediately preceding transport unit TE_{i+1} , wherein also a plurality of preceding transport units TE_k may be monitored. In particular, in the case of switches W a collision may also take place with a transport unit TE_k coming from another transport portion FA_i of the transport path 2, which need not to be the immediately preceding transport unit TE_{i+1} . If in one time compliance with safety requirements cannot be ensured anymore for a transport unit TE_i , the transport unit control 3 activates an appropriate action.

An action may be the activation of a stopping maneuver, i.e. particular or all transport units TE_i are stopped, or the execution of a matching maneuver, i.e. the movement of a transport unit TE_i is adapted to the movement of another transport unit TE_k , in particular a directly preceding transport unit TE_{i+1} .

The operation of monitoring the safety settings is described based on a phase space representation, whereby the safety function is in the following also called the phase space limitation. The phase space is, as known, a representation of the three states of a movement, i.e. position p , speed v and acceleration a , in a diagram. The phase space may also comprise other states, as for example the jerk (time-derivative of acceleration) and/or variation of jerk over time (second time-derivative of acceleration).

Fig.2 shows the phase space projected on the plane of speed v and position p for seven transport units TE_i , $i = 1, \dots, 7$, which are positioned on a transport portion FA_i . The transport units TE_i move for example for simplicity's sake each with a constant acceleration ($a_i = 0$), but with different speed v_i , not equal zero, and are in different positions p_i . The respective current position p_i^* and speed v_i^* are marked by circles. In each cycle step n it is now preemptively calculated if for a transport unit TE_i it is possible to execute a stopping maneuver, without this transport unit TE_i collides with a preceding transport unit TE_k , $k > i$, in particular the directly preceding transport unit TE_{i+1} . Normally the compliance with a certain safety distance may also be checked in that way. All that is behind the transport unit TE_i can then be ignored, since it can be assumed that the transport units TE_i behind perform the same verification. Now, for a transport unit TE_i in each cycle step n for the calculated new setpoint position p_i the stopping distance ρ_i is calculated, therefore the distance required by the transport unit TE_i to go from current speed v_i^* to stop ($v_i = 0$). The position $p_i(v_i=0)$ in which the transport unit TE_i stops, is also called the stopping point. Such a stopping maneuver is performed with a predetermined stopping deceleration a , which normally corresponds to the maximum possible acceleration a_{max} , but should not be lower than an acceleration, with which the transport unit TE_i can be decelerated during a normal movement. The stopping point $p_i(v_i=0)$ may be easily calculated and obviously depends from how the stopping maneuver for the transport unit TE_i is cinematically implemented, which is considered known.

At this point it has to be noted that the use of setpoints S for the phase space limitation is advantageous, since these are anyway present in the transport unit control 3. In the same way, current actual values of movement of transport unit TE_i may also be used for the phase space limitation. The actual values have however somehow to be detected with a measuring system or calculated, which is onerous. Moreover it is also possible to provide a lag error monitoring, which continuously monitors the deviation of actual values from setpoints S and engages, when this deviation becomes too great. Also for this reason the use of setpoints S for phase space limitation is no limitation. The use of setpoints or actual values is therefore considered equivalent.

In a simple case, a stopping maneuver, for example is executed with a constant maximum acceleration $a_{i,max}$ and the transport unit TE_i is therefore decelerated until the speed $v_i=0$ is achieved. From the cinematic relationships it may easily be deduced that then time Δt_i until stopping

of transport unit TE_i derives from $\frac{|v_i^*|}{a_{i,max}}$, wherein v_i^* indicates the speed at the beginning of de-

celeration. The stopping distance ρ_i of the transport unit TE_i then derives from $\rho_i = \frac{v_i^*}{2} \Delta t$ or

$\rho_i = \frac{v_i^* \cdot |v_i^*|}{2 \cdot a_{i,max}}$. Depending on the cinematic implementation of the stopping maneuver SM_i the

calculation of the stopping distance ρ_i may also take place in another way. For example, for the stopping maneuver SM_i a speed profile may be set, with which a better convergence to the end speed $v_i=0$ may be achieved. A limitation of acceleration variation may also be provided, in order to generate no (excessively) jerky movements of the transport unit TE_i.

In this way a criterion for executing a stopping maneuver SM_i for a transport unit TE_i in a cycle step n may involve checking the inequation

$$p_i^* + \rho_i [+M] \leq p_k^* + \rho_k$$

in order to avoid a collision with a preceding transport unit TE_k. Naturally it is also possible to provide a minimum distance M to be observed. The minimum distance M may contain a safety reserve, but also the dimensions of transport unit TE_i may be modelled with the minimum distance M . In the same way, the minimum distance M may also consider the lag errors (i.e. the deviation between setpoint position and actual position of transport unit TE_i).

In general terms, it is checked, if the one transport unit TE_i and a preceding transport unit TE_k get too close to one another during a presumed stopping maneuver SM_i, SM_k, which for example may be checked through the stopping points $p_i(v_i=0)$, $p_k(v_k=0)$ or the stopping distances ρ_i , ρ_k . How close the transport units TE_i, TE_k may come, may be defined through the minimum distance M , for example. If they come too close, a stopping maneuver SM_i is activated.

According to a cinematic implementation for the execution of stopping maneuver SM_i, it may also happen, that the transport unit TE_i cannot be stopped at the first reaching of speed $v_i=0$. An example for this is the implementation of a jerk-filter (limitation of admissible acceleration variation) formed by an averaging filter. This may lead to the fact that a transport unit TE_i in fact reaches speed $v_i=0$, but the movement in this point cannot be interrupted, but has to be prolonged with an inverted velocity. Therefore the transport unit TE_i in this case is forcibly moved over this inversion point $p_i(v_i=0)$ when reaching speed $v_i=0$ for the first time, and is further moved with inverted speed in the opposite direction. The implementation of the cinematic movement of the stopping maneuver then ensures that the transport unit TE_i is stopped with an inverted velocity. The end point $p_i''(v_i=0)$ is then reached by repeated reaching of speed $v_i=0$. Assuming that the phase space limitation again ensures that the behind transport unit TE_i does not collide with a preceding transport unit TE_k, the stopping distance ρ_i in this case is obtained from the minimum distance between the starting position p_i^* of the stopping maneuver and the inversion point $p_i'(v_i=0)$ and end point $p_i''(v_i=0)$, therefore $\rho_i = \text{Min}\{p_i'(v_i=0) - p_i^*, p_i''(v_i=0) - p_i^*\}$. In the same way, in this case the stopping point $p_i(v_i=0)$ of the transport unit TE_i is obtained as a min-

imum of inversion point $p_i'(v_i=0)$ and end point $p_i''(v_i=0)$. This is shown in Fig.2 with transport units TE4, TE6. Otherwise, in this case there is no difference from the above.

In the same way, it is irrelevant in which direction preceding transport unit TE k is moving, as indicated in Fig.2 by means of transport units TE5 and TE6. This means also that the phase space limitation advantageously considers also transport units TE k , which move in the opposite direction. The speed v_i has only to be considered with the correct sign, which is easily accomplished.

Fig.2 also shows a barrier B. This is for example the inlet area of a switch W, which can only be passed, when the switch W is released for a transport unit TE i , for example through a superordinate transport assembly control 5. The stopping distance ρ_B of a barrier B may be considered as zero and the current position p_B^* of barrier corresponds therefore to a stopping point p_B ($v=0$), wherein the position p_B^* of barrier naturally is a predetermined position. In this way it is possible, for example, to use again above inequation for the checking, i.e. $p_i^* + \rho_i [+M] \leq p_B^*$ in order to avoid a collision with the barrier B, wherein again a minimum distance M may be considered.

Therefore, for collision monitoring of phase space limitation an extreme case is considered, in which it is assumed that a transport unit TE k , $k>i$ executes a stopping maneuver SM k according to a predetermined cinematic movement, for example, with a maximum possible acceleration a_{max} , or that on the transport path 2 a barrier B is provided, which cannot be passed. It has to be ensured then that a transport unit TE i moving behind on the transport path 2 in the transport direction may be stopped with a predetermined stopping maneuver SM i , without a collision with the preceding transport unit TE k or the barrier B. In this way, it is ensured that the transport units TE i of transport assembly 1 may be stopped at any moment, without collisions, or that the two transport units TE i , TE k or the transport unit TE i and the barrier B don't come too close to each other.

If in continuous operation the previously calculated stopping points $p_i(v_i=0)$ and $p_k(v_k=0)$ of two transport units TE i , TE k , possibly considering an inversion point p' and end point p'' as previously described, or the previously calculated stopping point $p_i(v_i=0)$ of a transport unit TE i and the stopping point $p_B(v=0)$ of a barrier B come too close to each other, possibly considering a minimum distance M, then a stopping maneuver SM i is executed for the transport unit TE i . Checking of the condition "get too close" may be executed in an adequate way, for example with the above inequalities. This stopping maneuver SM i may not directly affect the other transport units TE i of the transport assembly 1 yet, i.e. those may initially proceed their normal movement. Such a stopping maneuver SM i may however force following transport units TE i to also execute a stopping maneuver SM i . The execution of a stopping maneuver SM i may also be considered

as a case of failure, which causes the stopping of a transport portion FAi or the entire transport assembly 1.

For monitoring a speed limitation a stopping maneuver SMi of a transport unit TEi is also assumed and in each cycle step n it is preemptively checked if the speed v_i of a transport unit TEi may be securely reduced with a stopping maneuver SMi from a current actual speed v_i^* to the limit speed v_G predetermined by the speed limitation (indicated by the dashed area in the phase space of Fig.3), for example in an area of transport portions FAi on which the transport unit TEi is currently moving, as shown in Fig.3. The part of the stopping maneuver SMi until reaching the limit speed v_G is indicated as a braking distance ε_i . The braking distance ε_i may be calculated again from known concrete cinematic implementation of the stopping maneuver SMi. If for example a deceleration of the transport unit TEi with a constant maximum acceleration $a_{i,max}$ is

again assumed, then the braking distance is derived as $\varepsilon_i = \frac{v_i^* - v_G}{2} \Delta t$ or

$$\varepsilon_i = \frac{(v_i^* - v_G) \cdot |v_i^* - v_G|}{2 \cdot a_{i,max}}.$$

In this way, for transport unit TEi in each cycle step n for a given

speed limitation it may be checked, if the inequation

$$p_i^* + \varepsilon_i [+M] \leq p_G$$

still holds, wherein p_G indicates the predetermined position of the speed limitation on transport portion FAi and p_i^* is the actual position of transport unit TEi. As shown, a certain minimum distance M may again be set. If above said condition cannot be met for a transport unit TEi, then for the transport unit TEi a stopping maneuver SMi for stopping the transport unit TEi is activated, which may also indicate a fault in operation of transport assembly 1. As explained above, this can also activate a stopping maneuver SMi of the following transport units TEi, as soon as the phase space limitation for these transport units TEi reacts.

Alternatively, a speed position $p_i(v_i=v_G)$ could also be calculated and checked, if the speed position $p_i(v_i=v_G)$ and the predetermined position p_G of speed limitation get too close to each other, which in turn may be defined by the minimum distance.

A local speed limitation is however not necessarily statically defined, but it can be provided, that the local speed limitation is dynamically activated and deactivated, for example through the transport assembly control 5 or in a defined temporal pattern. In order to manage these dynamic speed limitations, these can initially be considered as static and may be monitored by the phase space limitation. If however it is clear or known, that for a transport unit TEi, the speed limitation will not be active until the area of speed limitation is left, then the speed limitation for transport unit TEi may be ignored.

It is also conceivable, that a speed limitation is defined only for a certain, or even more certain, transport unit TE_i . In this way it could be possible, for example, to let the speed limitation be dependent from the state, for example the load, of the transport unit TE_i . In case of heavy loading, for example, in a curve, a speed limitation can be valid, whereas an empty transport unit TE_i has not to comply with this limitation.

It can be provided, that for certain transport units TE_i the movement of the transport unit TE_i is adapted, without the need, in case of conflict, to immediately execute a complete stopping maneuver SM_i , i.e. to $v_i=0$. For a transport unit TE_i for example only a destination position may be defined, wherein the distance to the destination may be flexibly set by the transport unit control 3, for example in the form of a particular speed profile and complying with maximum values for speed and acceleration, and optionally also for jerk or jerk variation. In this way, the transport unit control 3, in which normally the phase space limitation is also implemented, may modify the movement of the transport unit TE_i whilst maintaining the destination position, in order to avoid a complete stopping maneuver SM_i . The phase space limitation may execute a matching movement, so that the safety settings are met. This case may occur, for example, when the immediately preceding transport unit TE_{i+1} is moving in the same direction but with a lower speed v_{i+1} , with respect to transport unit TE_i that moves with speed v_i . This would inevitably imply, that the phase space limitation will react sometime, since both transport units TE_i , TE_{i+1} will eventually get too close to each other. In this case the transport unit TE_i would be stopped with a stopping maneuver SM_i , although a simple speed adaption of transport unit TE_i would suffice.

The matching movement is described with reference to Fig.4. The transport unit TE_i moves here with speed v_i , which is greater than speed v_k of a preceding transport unit TE_k . Again, a stopping maneuver SM_i is assumed, which is preemptively calculated, wherein the stopping maneuver SM_i of transport unit TE_i in this case does not stop transport unit TE_i , i.e. decelerate it to final speed $v_i=0$, but is oriented on speed v_k of a preceding transport unit TE_k . The stopping maneuver SM_i again is performed according to a predetermined cinematic movement. The stopping maneuver SM_i in a simple case, for example, takes place again with a constant maximum acceleration $a_{i,max}$. For the matching movement, preferably a cinematic movement is implemented, which ensures a possibly jerk-free matching movement, as shown in Fig.4.

Initially (similar to calculation of braking distance ε_i) according to the concrete cinematic implementation of stopping maneuver SM_i the matching distance γ_i is calculated, which is required for braking the transport unit TE_i according to the cinematic implementation of the compensation movement from speed v_i to speed v_k of a preceding transport unit TE_k . In the same way, again a speed position $p_i(v_i=v_k)$ could be calculated, and used for the checking.

Now, the phase space limitation preferably fulfills two conditions. On one side both transport units TE_i , TE_k during a matching movement should not get so close, that due to phase space

limitation, a stopping maneuver SM_i as described with reference to Fig.1 is activated. This is indicated in Fig.4 by position p_i' and starting position p_k^* of transport unit TE_k when the transport unit TE_i has reached speed v_k . Therefore a safety distance S is set, which after execution of matching movement, has to be at least maintained between both transport units TE_i , TE_k , so that the transport unit TE_i is not stopped. At the same time, the safety distance S should be so long, that in case of a deceleration of the preceding transport unit TE_k with an acceleration which is higher than the acceleration for decelerating the transport unit TE_i (i.e. both transport units TE_i and TE_k get closer to each other during deceleration), the activation of a stopping maneuver SM_i for stopping the transport unit TE_i is avoided. The safety distance S may be determined through knowledge of the cinematic implementations of movements of transport units TE_i , TE_k .

In this way a matching movement may be activated, for example, if the condition

$$(p_k^* - p_i^*) - \gamma_i [+M] \leq S$$

is violated. In this way it can be ensured that a matching movement can be executed without the phase space limitation activating a stopping maneuver SM_i for stopping the transport unit TE_i .

The matching movement may be easily implemented in the transport unit control 3 in an advantageous embodiment for example in that for the transport unit TE_i a new maximum speed $v_i = v_k$ is set.

If the matching movement is cinematically implemented in a different way, rather than a stopping maneuver for stopping the transport unit TE_i , for example, because a soft approaching to the final speed v_k is desired, a further improvement potential may be utilized. It is assumed that the preceding transport unit TE_k during the matching movement executes a stopping maneuver SM_k . In this case, the transport unit TE_i would initially execute the soft matching movement, until the phase space limitation kicks in, and the transport unit TE_i is stopped with a stopping maneuver SM_i . If the transport unit TE_i had immediately performed a stopping maneuver SM_i , then it would have come earlier to a stop, whereby instead of the matching movement at a later time a stopping maneuver SM_i could have been immediately executed. In this way the transport assembly 1 would possibly transition later in an undesired failure state, which can be sufficient to let potential conflict situations along the transport path 2 to automatically solve, before the phase space limitation kicks in.

Also a locally defined speed limitation may also be treated with a matching movement, as described in Fig.5. If on the transport path 2 a speed limitation to speed v_G is provided, then a matching movement with a matching distance γ_i is executed for example, if the condition

$$(p_G^* - p_i^*) - \gamma_i [+M] \leq S$$

is violated. A minimum distance M and/or a safety distance S may again be considered. After the speed limitation, the speed of transport unit TE_i may be increased again, if necessary, for example through setting in the transport unit control 3, as shown in Fig.5.

With above explained concepts switches W may also be treated, as described by means of Fig.6 and Fig.7. A conflict zone K is assigned to a switch W , inside which only a stopping point $p_i(v_i=0)$ of a single transport unit TE_i may be present, since otherwise in case of stopping maneuvers SM_i a collision between transport units TE_i in the switch area may happen. For managing switches the stopping maneuvers SM_i of transport units TE_i are preemptively calculated and evaluated.

Fig. 6 shows, from the point of view of the transport direction of transport unit TE_1 diverging switches W_1, W_2, W_3 with assigned conflict zones K_1, K_2, K_3 , at which the transport unit TE_i may select between a plurality of transport portions FA_1, FA_2, FA_3, FA_4 of transport path 2. A transport unit TE_2 with the same transport direction as the transport unit TE_1 , but on a transport portion FA_2 , on which the transport unit TE_1 shall not be moved, can be ignored, since no collision can take place. A transport unit TE_3 with opposed movement direction is however treated as if it is positioned on the same transport portion FA_1 as transport unit TE_1 . Additionally, it has also to be ensured that in case of stopping maneuvers SM_i , only one of the two transport units TE_1, TE_3 may enter the conflict zone K_2 of switch W_2 , which is assigned to both transport portions FA_1, FA_2 . Otherwise above said phase space limitation ensures that both transport units TE_1, TE_3 do not collide on the transport portion FA_1 .

Fig.7 shows, from the point of view of the transport direction of transport unit TE_1 converging switches W_1, W_2 , with assigned conflict zones K_1, K_2 , where transport units TE_i from a plurality of transport portions FA_1, FA_2, FA_3 are converged onto a transport portion. A transport unit TE_3 on another transport portion FA_3 than the transport unit TE_1 and with a transport direction which is opposite to transport unit TE_1 , can be ignored, since no collision can happen. A transport unit TE_4 , which moves on the same transport portion FA_1 as transport unit TE_1 , but in the opposite transport direction has to be considered. If for instance the transport unit TE_4 should move at switch W_1 on the same transport portion FA_1 as the transport unit TE_1 , above said phase space limitation kicks in. If the transport unit TE_4 should move in the switch W_1 on another transport portion FA_2 , then only one of both transport units TE_1, TE_4 in case of a stopping maneuver SM_1, SM_4 may enter the conflict zone K_1 of switch W_1 , which is assigned to both transport portions FA_1, FA_2 . A transport unit TE_2 , which moves in the same direction as transport unit TE_1 , but on another transport portion FA_2 , has also to be considered, if both transport portions FA_1, FA_2 converge at a switch W_1 . In this case, only one of the two transport units TE_1, TE_2 can enter, in case of a stopping maneuver SM_1, SM_2 , the conflict zone K_1 of switch W_1 , which is assigned to both transport portions FA_1, FA_2 .

The treatment of switches $W1$, $W2$, $W3$, as described above, may for example be handled through setting barriers B for certain transport units TE_i . If a collision may take place between two transport units TE_i in the switch area or in a conflict zone K of a switch W in case of stopping maneuvers SM_i , then for one of transport units TE_i involved, a barrier B may be set,
 5 whereby the normal phase space limitation ensures that this transport unit TE_i does not pass barrier B . Barrier B may be removed again, if the collision risk is absent again. Therefore switches do not need further mechanisms for phase space limitation, as those explained above. Only a program logic has to be implemented, which executes the setting and removing of temporary barriers B according to above said conditions.

10 The phase space limitation may naturally also use knowledge regarding the transport path 2. There may be transport portions FA_i , for example, where no stopping maneuver SM_i may take place. An example is a transport portion FA_i in which a mechanical coupling with a robot exists, since the robot executes work on a piece on a transport unit TE_i . In this case, for example a matching movement could be delayed, since it has not to be considered that a preceding
 15 transport unit TE_k executes a stopping maneuver SM_k in such a transport portion FA_i .

In the same way, the phase space limitation could use knowledge of a superordinate transport assembly control 5, with routing calculations, switch arbitration, deadlock avoidance, control of temporary barriers, etc. Assuming that the phase space limitation causes for a transport unit TE_i a stopping maneuver SM_i (also as a matching movement) on the basis of a set temporary barrier B , however knows, that this barrier B will certainly open in the near future. Then the phase
 20 space limitation may also avoid such a stopping maneuver SM_i . An example for this may be the control of access of a transport unit TE_i to a transport segment FS_i through temporary barriers B . The access of a transport unit TE_i is preemptively controlled, for example in the transport assembly control 5. The phase space limitation avoids passing of barrier B . The set barrier B may then forward to the phase space limitation also the information, about when the barrier is safely
 25 removed again, for example because a preceding transport unit TE_k will have safely left the transport segment FS_i . In this way, the phase space limitation for a transport unit TE_i may activate a stopping maneuver SM_i in spite of a set barrier B optionally later, since it is clear, that a preceding transport unit TE_k will have left the transport segment FS_i , before the transport unit
 30 TE_i enters with the stopping maneuver the transport segment FS_i (and therefore no barrier B would be set anymore).

Similarly, assumptions regarding the planned or executed movement of other transport units TE_i may help to improve different interventions by the phase space limitation. If for example it is sure, that the transport unit TE_k of Fig.4 will accelerate sufficiently, then this can cause the
 35 phase space limitation to avoid activating the matching maneuver at all.

In a simplified embodiment, it may also be envisaged to not check for a transport unit TE_i the compliance of safety requirements by means of the stopping maneuver SM_i in each cycle step n, but at longer intervals, for example only after each x-th cycle step x·n.

5 The implementation of monitoring the safety requirements may for example be implemented as schematically shown in Fig.8. In this case it is assumed that the phase space limitation 10 is implemented in a transport unit control 3. The transport unit control 3 either receives directly set-
points S for moving a transport unit TE_i, for example from a superordinate transport assembly control 5, or receives a target setting Z for movement, for example a target speed or a target
10 position. If a target setting Z is set, then also a movement profile unit 11 may be provided in the transport unit control 3, which converts the target setting Z in setpoints S of movement, for example in the form of a speed profile. These alternative possibilities are indicated in Fig.8 by the toggle S1. The setpoint S is used for controlling the drive coils AS_{ij}, for example through a segment control unit 4.

The setpoint S is however also used in a phase space limitation 10, in order to monitor the
15 compliance with the safety settings for a transport unit TE_i, as described above. To this end it is assumed, that the phase space limitation 10 has all information required, as for example the knowledge about the movement of preceding transport units TE_k, local speed limits, barriers, etc. If the phase space limitation 10 kicks in on the basis of the setpoint S, then the phase space limitation 10 engages and conducts a stopping maneuver SM_i for the transport unit TE_i.
20 To this end, the phase space limitation 10 sets the setpoints S(SM_i) for the stopping maneuver SM_i. This is indicated by the toggle S2 in Fig.8. The stopping maneuver SM_i may cause, as explained, the stopping of the transport unit TE_i, or may also be implemented as matching movement.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for operating a transport assembly in the form of a long stator linear motor, in which a plurality of transport units (TE_i) are moved along a transport path, wherein the movement of the transport units (TE_i) along the transport path is controlled by setting setpoints (S) of movement through at least one transport unit control;

wherein for at least one first transport unit (TE_i) it is preemptively determined, if for the transport unit (TE_i) a stopping maneuver (SM_i) may be executed with a predetermined cinematic, so that:

a) a collision of this transport unit (TE_i) with a preceding second transport unit (TE_k) or with a barrier (B) of the transport path is avoided; or

b) exceeding of a predetermined local speed limitation (v_G) in a position (p_G) of the transport path by the first transport unit (TE_i) is avoided; or

c) a matching movement of the first transport unit (TE_i) to a speed (v_k^*) of a preceding second transport unit (TE_k) is possible; and

wherein the stopping maneuver (SM_i) of the first transport unit (TE_i) is effectively activated, when at least one of these conditions is violated.

2. The method according to claim 1, wherein for the preceding second transport unit (TE_k) a stopping maneuver (SM_k) is assumed and it is checked, if the first transport unit (TE_i) during an assumed stopping maneuver (SM_i) gets too close to the second transport unit (TE_k).

3. The method according to claim 2, wherein for the first transport unit (TE_i) and for the second transport unit (TE_k) on the basis of the knowledge of the cinematic implementation of the respective stopping maneuver (SM_i, SM_k) a stopping point ($p_i(v_i=0)$, $p_k(v_k=0)$) or a stopping distance (ρ_i , ρ_k) is calculated and these are compared, in order to determine, if the first transport unit (TE_i) and the second transport unit (TE_k) get too close to each other.

4. The method according to claim 1, wherein it is checked, if the first transport unit (TE_i) during an assumed stopping maneuver (SM_i) gets too close to the barrier (B).
5. The method according to any one of claims 2 to 4, wherein a minimum distance (M) is set, which indicates how close the transport unit (TE_i) can get to the preceding transport unit (TE_k) or the barrier (B).
6. The method according to claim 1, wherein it is checked, if the speed (v_i) of the first transport unit (TE_i) during an assumed stopping maneuver (SM_i) may be reduced from a current actual speed (v_i^*) to a limit speed (v_G) set by the speed limitation, without the first transport unit (TE_i) getting too close to the defined area of speed limitation.
7. The method according to claim 6, wherein for the first transport unit (TE_i), from the knowledge of the cinematic implementation of the stopping maneuver (SM_i) a speed point ($p_i(v_i=v_G)$) or a braking distance (ϵ_i) is calculated and therefore it is determined if the speed (v_i) of the transport unit (TE_i) may be reduced to the limit speed (v_G) before the area of speed limitation.
8. The method according to claim 6 or 7, wherein a minimum distance (M) is set, which indicates how close the transport unit (TE_i) may get to the area of speed limitation.
9. The method according to claim 1, wherein it is checked, if the speed (v_i) of the first transport unit (TE_i) in case of an assumed stopping maneuver (SM_i) may be reduced from a current actual speed (v_i^*) to a speed (v_k) of the second transport unit (TE_k), so that between the first transport unit (TE_i) and the second transport unit (TE_k) a safety distance (S) is maintained, which is obtained from the concrete cinematic implementation of the stopping maneuver (SM_i).
10. The method according to claim 9, wherein for the first transport unit (TE_i), from the knowledge of the cinematic implementation of the stopping maneuver (SM_i) a speed point ($p_i(v_i=v_G)$) or a matching distance (γ_i) is calculated and it is determined if the speed

(v_i) of the first transport unit (TE_i) may be reduced to the speed (v_k) of the second transport unit (TE_k).

11. The method according to claim 9 or 10, wherein in addition to the safety distance (S) a minimum distance (M) to be maintained is considered.

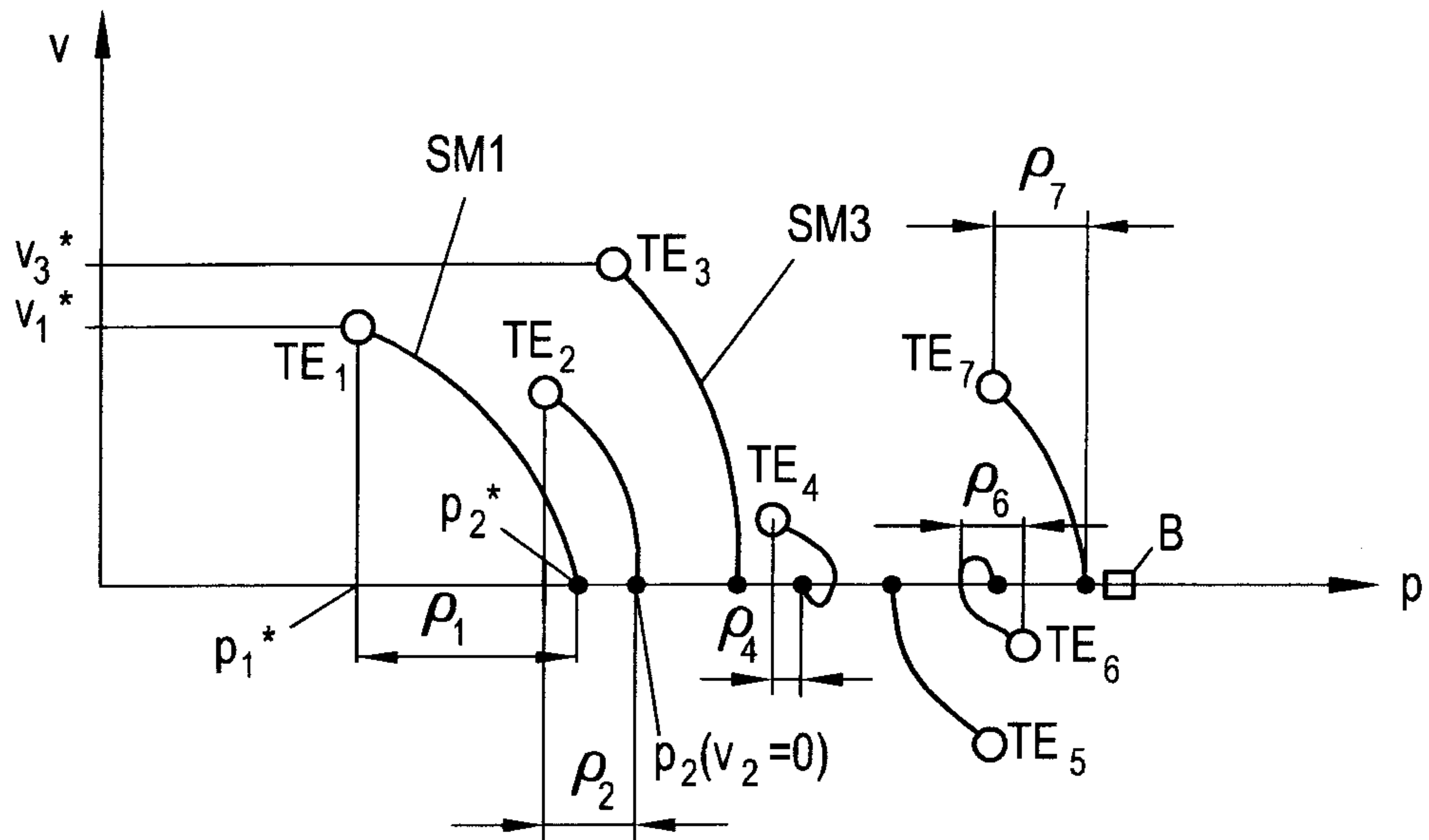


Fig. 2

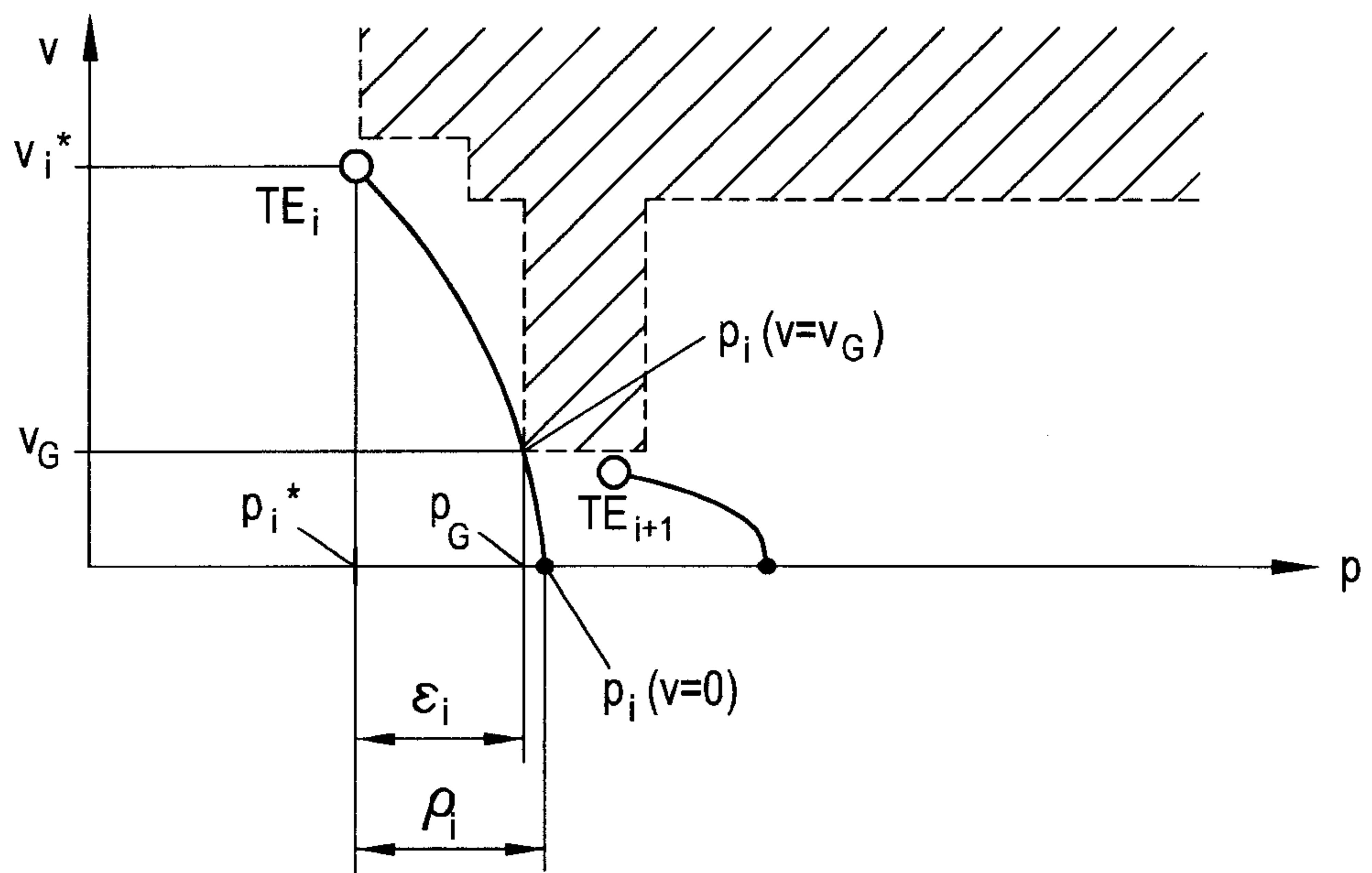


Fig. 3

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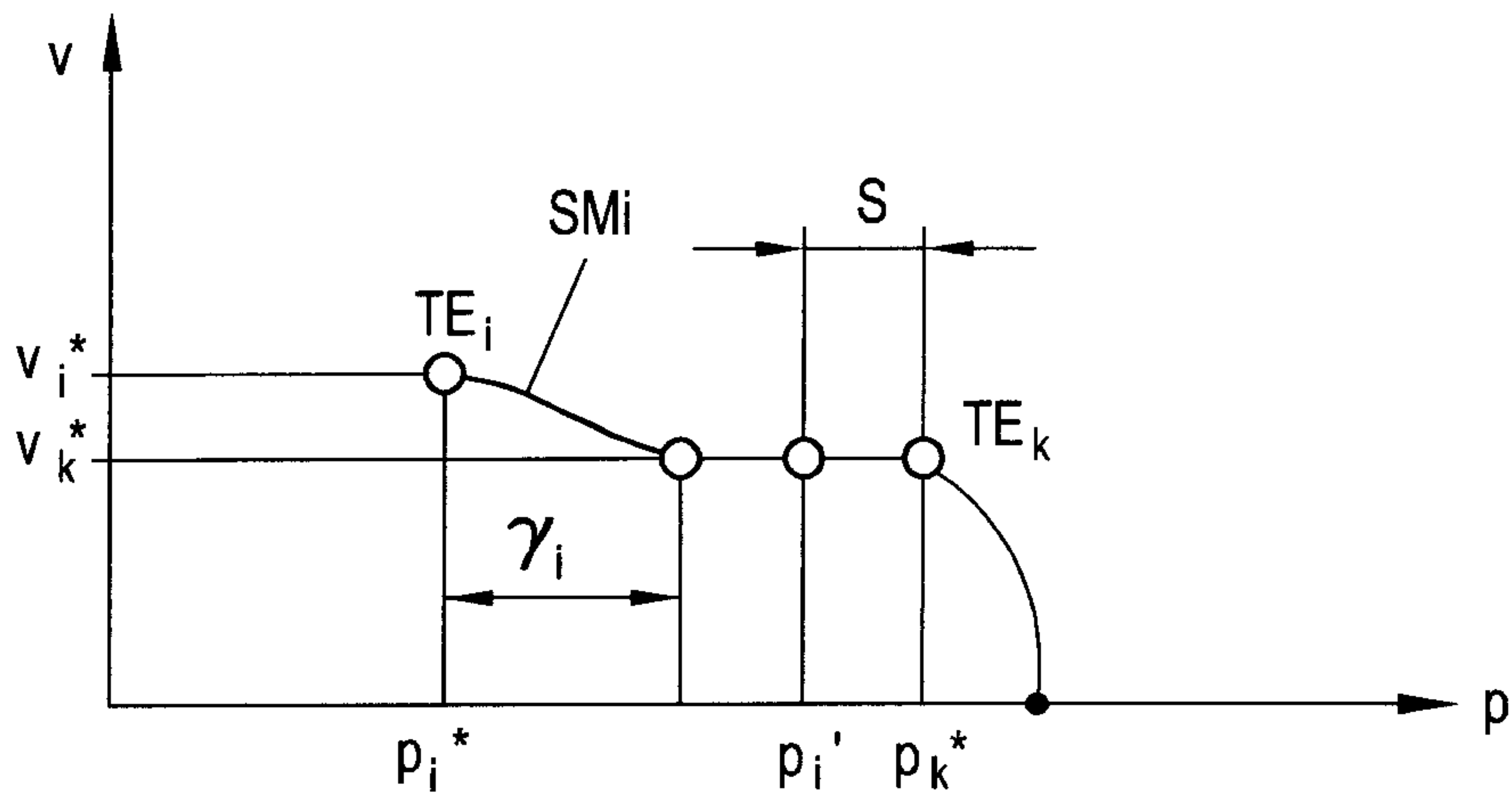


Fig. 4

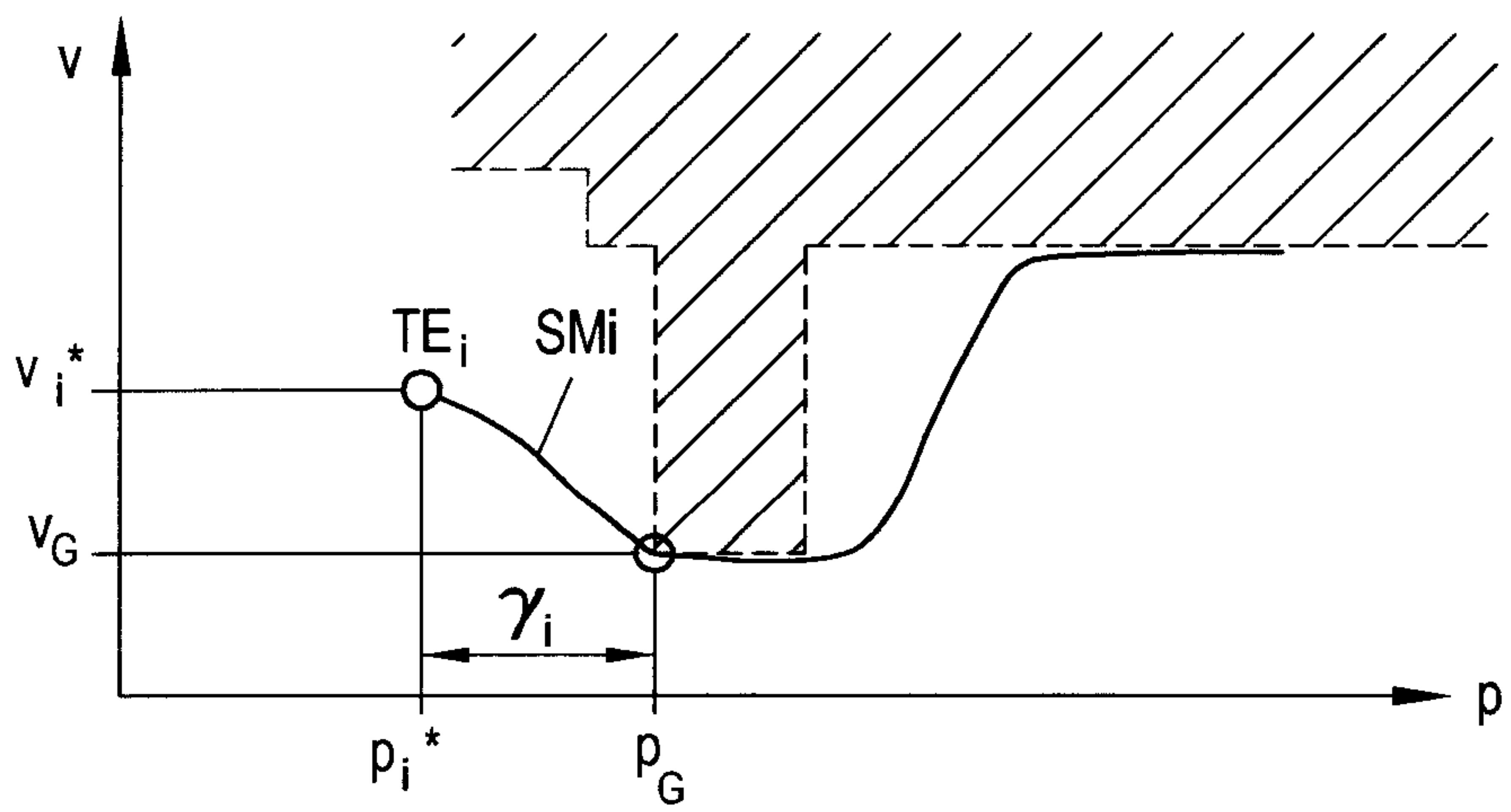


Fig. 5

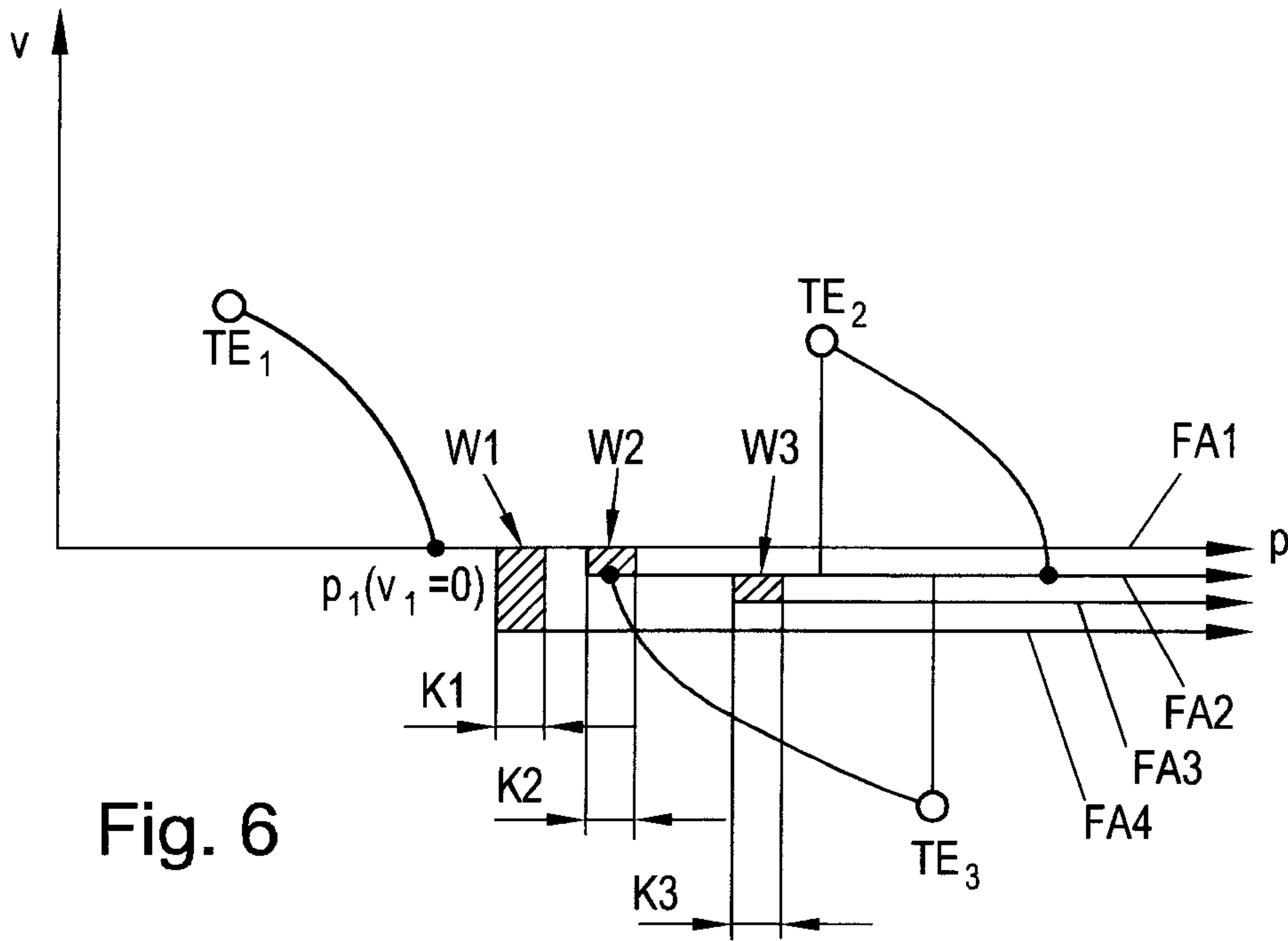


Fig. 6

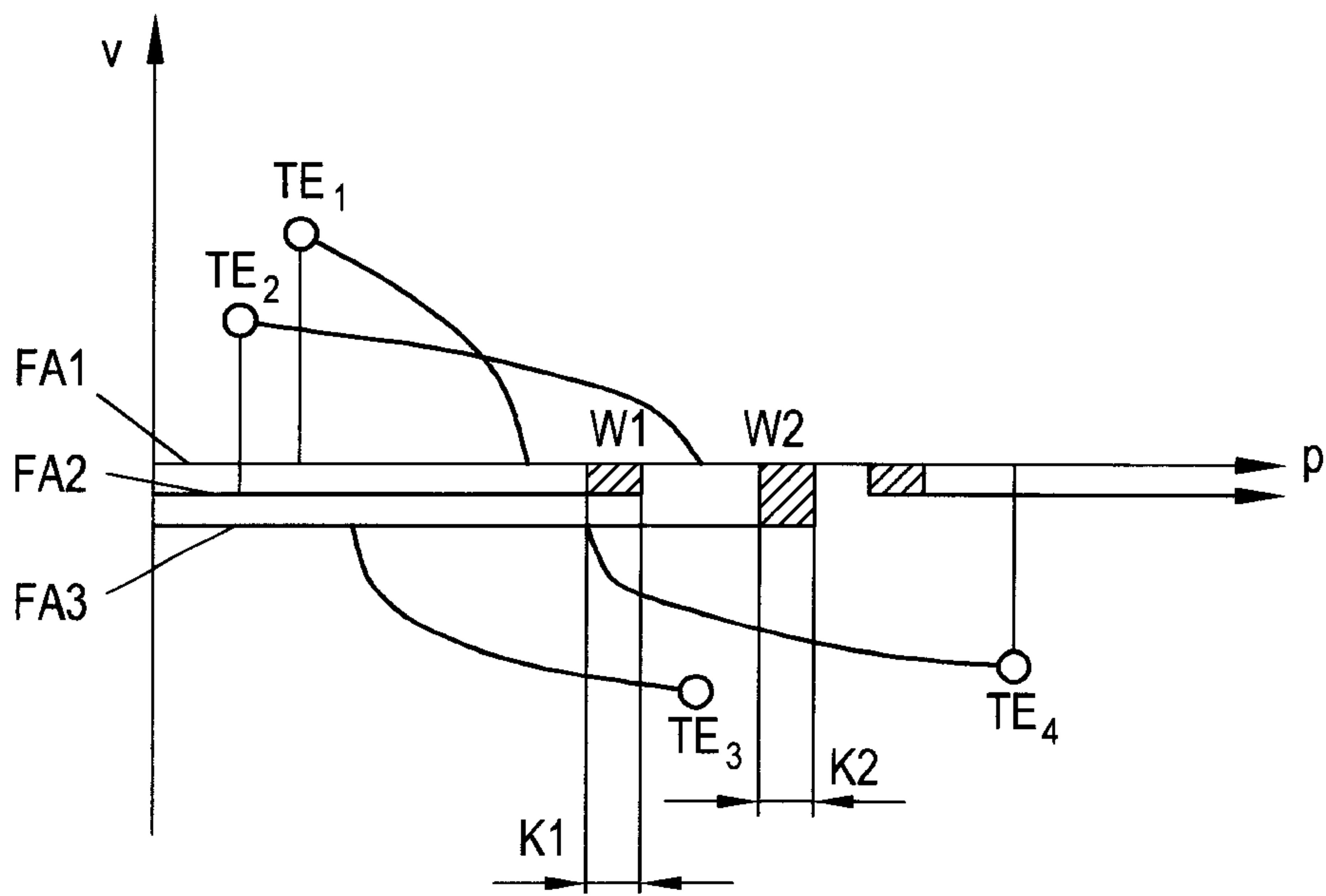


Fig. 7

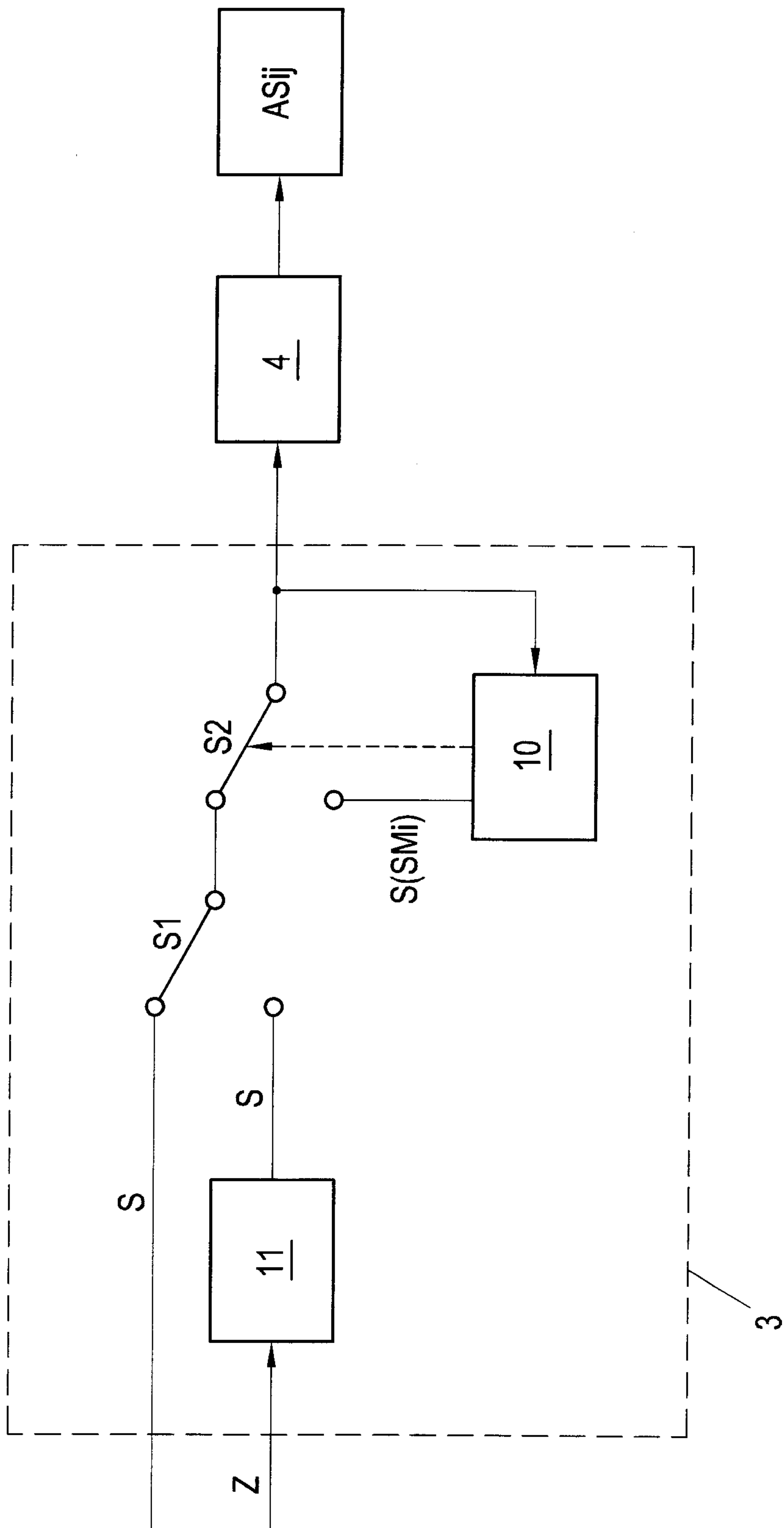


Fig. 8

