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(54) **A method of controlling transversal resonance in a catenary, a hoist drum control system and a mine drum hoist system**

(57) The present disclosure relates to a method of controlling transversal resonance in a catenary of a mine drum hoist system (1) comprising a hoist drum (5) having Lebus grooves, a head sheave (7), a rope (9) having a catenary (9a) extending between the hoist drum (5) and the head sheave (7) and a vertical rope portion (9b), and a conveyance (11) attached to the vertical rope portion (9b). The method comprises a) determining a current payload of the conveyance (11), b) obtaining a hoist speed of the hoist drum (5), corresponding to a first speed of the conveyance (11), c) determining a transversal res-

onance position along the vertical rope portion (9b) at which transversal resonance is generated in the catenary (9a) when reached by the conveyance (11) with the current payload and first speed, wherein the transversal resonance position is determined based on the current payload and on the hoist speed, and d) reducing the first speed of the conveyance in a speed reduction zone which includes the transversal resonance position. This disclosure also relates to a computer program, a hoist drum control system (3), and a mine drum hoist system (1).

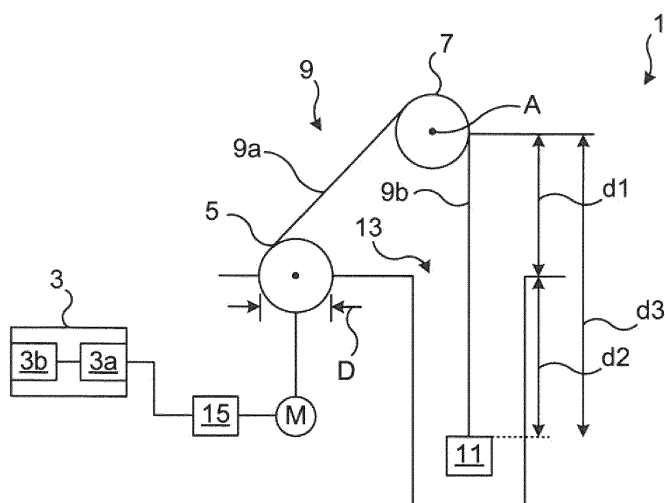


Fig. 1

Description**TECHNICAL FIELD**

5 **[0001]** The present disclosure generally relates to mine drum hoist systems. In particular, it relates to control of a hoist drum of a mine drum hoist system.

BACKGROUND

10 **[0002]** Hoist drums which coil the rope in more than one layer normally have Lebus grooves in which the rope is laid. The grooves are parallel except in the cross-over sections in which the groove moves the rope in the axial direction of the drum a distance which is equal to half the rope diameter, to the next parallel groove. There are two cross-over sections on the circumference of the drum surface which means that after a full revolution the rope has been moved by the Lebus groove one rope diameter. Normally the cross-over sections are diametrical. This arrangement is called symmetric Lebus.

15 **[0003]** The drum is normally mounted near the ground surface. The rope runs from the drum to a head sheave in the head frame above the mine shaft. The rope angle between the drum and the head sheave is normally in the order of 45 degrees. After passing over the head sheave the rope runs vertically in the mine shaft. The rope end is connected to a conveyance for transport of personnel, mineral or equipment. The part of the rope that is between the hoist drum and the head sheave is called catenary.

20 **[0004]** The cross-over section pushes the rope over in a short time creating a near rectangular pulse-shaped "kick" on the rope in a direction perpendicular to the rope axis, also called transversal kick. The pulse wave can be converted to a fundamental sine wave with harmonics by means of Fourier transformation. If the kick is repeated, i.e. excited with a frequency that corresponds to the natural or resonance frequency of the catenary the amplitude of the transversal catenary oscillations will build up to large unacceptable values. High amplitudes will severely affect the rope life. Moreover,

25 high amplitudes can provide discomfort to personnel traveling with the conveyance.
[0005] It is known that by reducing the hoisting, i.e. rope speed when the rope pull is near a point where catenary resonance would be generated at that maximum speed, the resonance point will shift to another rope pull since at the reduced speed the excitation or kick frequency of the Lebus on the drum will be reduced.

30 **[0006]** For hoists which always run at nominal full speed and with constant load in the up direction and with zero payload in the down direction, which is the case for production hoists, it is normally sufficient to have a pre-set distance in the mine shaft where the hoisting speed is reduced. However, this is not sufficient in case the payload and the speed of the conveyance vary.

SUMMARY

35 **[0007]** An object of the present disclosure is to solve, or at least mitigate, the problems of the prior art.

[0008] Hence, according to a first aspect of the present disclosure there is provided a method of controlling transversal resonance in a catenary of a mine drum hoist system comprising a hoist drum having Lebus grooves, a head sheave, a rope having a catenary extending between the hoist drum and the head sheave and a vertical rope portion, and a conveyance attached to the vertical rope portion, wherein the method comprises: a) determining a current payload of the conveyance, b) obtaining a rotation speed of the hoist drum, corresponding to a first speed of the conveyance, c) determining a transversal resonance position along the vertical rope portion at which transversal resonance is generated in the catenary when reached by the conveyance with the current payload and first speed, wherein the transversal resonance position is determined based on the current payload and on the hoist speed, and d) reducing the first speed of the conveyance in a speed reduction zone which includes the transversal resonance position.

45 **[0009]** A technical effect obtainable by reducing the first speed of the conveyance in a speed reduction zone is that the resonance point is moved away from the transversal resonance point. As a result transversal resonance does not occur at the determined transversal resonance position. Moreover, since the first speed is maintained outside the speed reduction zone, a transversal resonance position that is moved due to speed reduction will never be realised, because it is moved to the originally determined transversal resonance position when the conveyance moves outside the speed reduction zone. Thus, transversal resonance in the catenary may essentially be avoided for any payload and any first speed of the conveyance. The payload and/or speed are thus allowed to vary each time the conveyance is hoisted in the mine shaft.

50 **[0010]** One embodiment comprises receiving a first force measurement from a first load cell of the head sheave and a second force measurement from a second load cell of the head sheave, wherein step a) involves determining a sum of force value by adding the first force measurement to the second force measurement, wherein the current payload is determined based on the sum of force value.

[0011] According to one embodiment the current payload is determined by subtracting the weight of the vertical rope

portion, the weight of the conveyance and the weight of the head sheave from the sum of force value.

[0012] According to one embodiment in step c) the determining of the transversal resonance position is further based on a resonance frequency of the catenary, a diameter of the hoist drum, a frequency of an impulse in the rope occurring at cross-overs of the Lebus grooves, a length of the vertical rope portion from a centre axis of the head sheave to a mine shaft opening, a weight of the conveyance, a rope weight per length unit and the length of the catenary.

[0013] According to one embodiment in step c) the transversal resonance position is obtained from a look-up table which contains pre-calculated transversal resonance positions for a plurality of different current payloads and first speed of the conveyance combinations.

[0014] According to one embodiment step d) of reducing the first speed of the conveyance involves reducing the hoist speed.

[0015] One embodiment comprises determining the speed reduction zone based on the hoist speed obtained in step b), wherein the determining of the speed reduction zone involves retrieving a speed reduction zone that has been determined for the transversal resonance position and which has been determined based on catenary side force values which are proportional to a difference between a first force measurement measured by a first load cell and a second force measurement measured by a second load cell.

[0016] According to a second aspect of the present disclosure there is provided a computer program product comprising computer-executable components which when executed by a processing system causes a hoist drum control system including the processing system to perform the method according to the first aspect.

[0017] According to a third aspect of the present disclosure there is provided a hoist drum control system configured to control transversal resonance in a catenary of a mine drum hoist system, wherein the hoist drum control system comprises a storage unit, and a processing system, wherein the storage unit comprises computer-executable components which when executed by the processing system causes the hoist drum control system to: determine a current payload of a conveyance, obtain a hoist speed of a hoist drum, corresponding to a first speed of the conveyance, determine a transversal resonance position along a vertical rope portion of a rope to which the conveyance is attached, at which transversal resonance position, at which transversal resonance position transversal resonance is generated in the catenary when reached by the conveyance with the current payload and first speed, wherein the transversal resonance position is determined based on the current payload and on the hoist speed, and reduce the first speed of the conveyance in a speed reduction zone which includes the transversal resonance position.

[0018] According to one embodiment the processing system is configured to receive a first force measurement from a first load cell of a head sheave and a second force measurement from a second load cell of the head sheave, wherein the processing system is configured to determine a sum of force value adding the first force measurement to the second force measurement, and wherein the processing system is configured to determine the current payload based on the sum of force value.

[0019] According to one embodiment the processing system is configured to determine the current payload by subtracting the weight of the vertical rope portion, the weight of the conveyance and the weight of the head sheave from the sum of force value.

[0020] According to one embodiment the processing system is configured to determine the transversal resonance position based on a resonance frequency of the catenary, a diameter of the hoist drum, a frequency of an impulse in the rope occurring at cross-overs of Lebus grooves of a hoist drum, a length of the vertical rope portion from a centre axis of the head sheave to a mine shaft opening, a weight of the conveyance, a rope weight per length unit and the length of the catenary.

[0021] According to one embodiment the processing system is configured to obtain the transversal resonance position from a look-up table which contains pre-calculated transversal resonance positions for a plurality of different current payloads and hoist speed combinations.

[0022] According to one embodiment the processing system is configured to determine the speed reduction zone based on the hoist speed, wherein the processing system is configured to determine the speed reduction zone by retrieving a speed reduction zone that has been determined for the transversal resonance position and which has been determined based on catenary side force values which are proportional to a difference between a first force measurement measured by a first load cell and a second force measurement measured by a second load cell.

[0023] According to a fourth aspect of the present disclosure there is provided a mine drum hoist system comprising: a hoist drum having Lebus grooves, a head sheave, a rope arranged to extend between the hoist drum and the head sheave to thereby define a catenary and a vertical rope portion, a conveyance arranged to be attached to the vertical rope portion, a motor arranged to operate the hoist drum, and a hoist drum control system according to the third aspect, arranged to control the motor.

[0024] Generally, all terms used in the claims are to be interpreted according to their ordinary meaning in the technical field, unless explicitly defined otherwise herein. All references to "a/an/the element, apparatus, component, means, etc." are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, etc., unless explicitly stated otherwise.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The specific embodiments of the inventive concept will now be described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a schematic example of a mine drum hoist system and a hoist drum control system;

Fig. 2 is a schematic front view of an example of a mine drum hoist system in Fig. 1;

Fig. 3a is a schematic side view of a detail of a head sheave in the mine drum hoist system in Fig. 1;

Fig. 3b is a schematic front view of a detail of the head sheave in Fig. 1;

Fig. 3c is a schematic front view of the hoist drum and the head sheave in Fig. 1;

Fig. 4 is a schematic diagram of a method of controlling transversal resonance in a catenary of the mine drum hoist system in Fig. 1; and

Figs 5a-5c show graphs of catenary side force values.

DETAILED DESCRIPTION

[0026] The inventive concept will now be described more fully hereinafter with reference to the accompanying drawings, in which exemplifying embodiments are shown. The inventive concept may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided by way of example so that this disclosure will be thorough and complete, and will fully convey the scope of the inventive concept to those skilled in the art. Like numbers refer to like elements throughout the description.

[0027] The present disclosure in general details how transversal resonance in a catenary may be avoided or at least reduced in a mine drum hoist system by determining a transversal resonance position along the vertical rope portion of a rope extending from the head sheave to a conveyance connected to the vertical rope portion, and by reducing the speed of the conveyance in a speed reduction zone that includes the transversal resonance position. The transversal resonance position is determined based on the current payload of the conveyance which is arranged to be hoisted in the mine shaft by means of a hoist drum, and on the desired speed at which the conveyance is to move in the mine shaft, in case the speed is pre-programmed, or on the actual current speed at which the conveyance moves in the mine shaft, in case the conveyance speed is operated manually.

[0028] By reducing the speed only in the speed reduction zone(s), in case there are several catenary transverse resonance points, the transversal resonance point(s) is/are moved away from the determined transversal resonance point(s).

[0029] This disclosure furthermore details which positions along the vertical rope portion should be categorised as transversal resonance positions in the control method, as there may be some transversal resonance positions that provide less significant transversal resonance in the catenary, where it is not necessary to reduce the speed of the conveyance. A tuning method in which the relevant transversal resonance point(s) is/are selected for the control method is therefore also disclosed herein. The tuning method also discloses how the speed reduction zone(s) is/are selected and how much the speed of the conveyance shall be reduced in the speed reduction zone(s).

[0030] Fig.1 depicts a mine drum hoist system 1 comprising a hoist drum 5, which is of Lebus type. The hoist drum 5 hence has a plurality of Lebus grooves 5a, as shown in Fig. 2. The Lebus grooves 5a have two cross-over sections per turn, as shown by means of the areas 5b and 5c in Fig. 2. Each cross-over section translates the Lebus grooves 5a for example half a rope diameter in the axial direction. In one turn each Lebus groove 5a is hence translated a rope diameter in the axial direction.

[0031] The drum hoist 5 may for example be a single drum hoist or a double drum hoists. Each of them can be equipped with one or two ropes that carry the conveyance.

[0032] The mine drum hoist system 1 further comprises a head sheave 7, a rope 9 and a conveyance 11. The rope 9 is coiled around the hoist drum 5, in one or more layers, for example three layers. The rope 9 extends from the hoist drum 5 to the head sheave 7. The rope 9 has a catenary 9a that extends between the hoist drum 5, about which the rope is coiled in the Lebus grooves 5a, and the head sheave 7. The rope 9 has a vertical rope portion 9b that runs from the head sheave 7 to the conveyance. The rope 9 is connected to or attached to the conveyance 11, so that when the hoist drum 5 is rotated and the rope 9 is coiled or uncoiled, the vertical position of the conveyance 11 is altered.

[0033] The mine drum hoist system 1 comprises a first load cell 7a and a second load cell 7b. The head sheave 7 is

equipped with the first load cell 7a and the second load cell 7b. The first load cell 7a and the second load cell 7b are utilised for determining a current payload of the conveyance 11 and a catenary side force on the head sheave 7.

[0034] A number of vertical distances are depicted in Fig. 1. A first distance d1 is defined as the vertical distance from the head sheave axis A to the mine shaft opening 13 which is the upper landing level for the conveyance 11. This first distance d1 is fixed, and is a known parameter. A second distance d2 is defined as the vertical distance from the mine shaft opening 13 to the top of the conveyance 11. The second distance d2 is at its maximum value when the conveyance is at the bottom landing level. A third distance d3 is determined as the distance from the head sheave axis A to the top of the conveyance 11, i.e. the sum of the first distance d1 and the second distance d2. It is normally the second distance d2 that determines a transversal resonance position along the vertical rope portion 9b, which will be described in more detail in the following. A transversal resonance position is a position along the vertical rope portion 9b at which transversal resonance is generated in the catenary 9a when reached by the conveyance 11 with a particular payload and speed.

[0035] The mine drum hoist system 1 comprises a hoist drum control system 3 having a processing system 3a and a storage unit 3b. The storage unit 3b comprises computer-executable components which when run on the processing system 3a causes the hoist drum control system 3 to perform the methods disclosed herein. In particular, the hoist drum control system 3 is configured to determine a current payload of the conveyance 11. The hoist drum control system 3 may for example determine the current payload based on a first force measurement and a second force measurement carried out by the first load cell 7a and the second load cell 7b, respectively.

[0036] The hoist drum control system 3 is moreover configured to obtain a hoist speed of the hoist drum 5 in metres per second, which is the speed of the conveyance 11, termed the first speed herein. The hoist speed may be a pre-programmed parameter for operating the conveyance 11, or it may be a real-time value obtained for example by measuring the number of revolutions per time unit of the hoist drum 5.

[0037] The hoist drum control system 3 is furthermore configured to determine a transversal resonance position along the vertical rope portion 9b at which transversal resonance is generated in the catenary 9a when reached by the conveyance 11 with the current payload and first speed, and to reduce the first speed of the conveyance 11 in a speed reduction zone which includes the transversal resonance position.

[0038] The transversal resonance position is determined by the hoist drum control system 3 based on the current payload and on the hoist speed. The transversal resonance position is equivalent to the second distance d2 for certain positions of the conveyance 11. By reducing the first speed of the conveyance 11 to a second speed in the speed reduction zone, by operating the hoist speed, the transversal resonance position is moved from that determined by the hoist drum control system 3 to a moved transversal resonance position. With moved transversal resonance position is meant the transversal resonance position to which the transversal resonance position is moved due to the reduction of the first speed. Catenary resonance will however not occur when the conveyance 11 reaches the moved transversal resonance position because the first speed is only reduced in the speed reduction zone.

[0039] The mine drum hoist system 1 may comprise a motor M and a drive unit 15. The hoist drum control system 3 may be configured to operate the motor M, e.g. via the drive unit 15 to thereby control the coiling speed and uncoiling speed of the rope 9, i.e. the hoist speed, from the hoist drum 5. As a result the speed of the conveyance 11 may be controlled.

[0040] Fig. 3a schematically shows a side view of the head sheave 7, one of the load cells, in this example the first load cell 7a, the catenary 9a and the vertical rope portion 9b. The total force, a sum of force value Ftot, measured by the first load cell 7a and the second load cell 7b is the sum of the force provided by the weight of the head sheave 7 and the vector sum of the rope pull force, i.e. the vertical component F_R and the catenary component F_R , which seen as vector components have different directions, but they both have the same magnitude, F_R .

[0041] According to one variation, the hoist drum control system 3 is arranged to determine the sum of force value by adding the first force measurement F_{La} to the second force measurement F_{Lb} , shown in Fig. 3b. The hoist drum control system 3 is according to one variation configured to determine the current payload based on the sum of force value Ftot, which is the absolute value of the vector addition of the first force measurement F_{La} and the second force measurement F_{Lb} . The current payload may be determined by subtracting the weight of the vertical rope portion 9b, the weight of the conveyance 11, and the weight of the head sheave 7 from the sum of force value Ftot. The catenary resonance frequency f_c , in particular the fundamental resonance frequency, may be expressed as

$$f_c = \frac{1}{2 \cdot L_C} \cdot \sqrt{\frac{F_R}{m_r}} \quad (1)$$

where L_C is the length of the catenary 9a and m_r is the weight of the rope in mass/length unit, e.g. kg/m. A transversal resonance in the catenary is obtained when an integer multiple of the fundamental rope kick frequency f_{exc} is equal to

the catenary resonance frequency f_C . The fundamental rope kick frequency may be expressed as

$$f_{exc} = 2 \cdot \frac{v}{\pi \cdot D} \quad (2)$$

where v is the hoist speed in metres/second, and D is the diameter of the hoist drum 5. In case there are several layers of rope coiled onto the hoist drum 5, these are also taken into account when calculating the fundamental rope kick frequency f_{exc} .

[0042] The rope pull force value may be expressed as $F_R = (m_c + m_l + d_3 \cdot m_r) \cdot g$, where m_c is the weight of the conveyance 11 and m_l is the current payload, the third distance $d_3 = d_1 + d_2$, and g is the gravitational acceleration. Thus from the relation $f_{exc} = f_C$ it can be deduced that

$$d_2 = \frac{\left(\left(\frac{4 \cdot v \cdot L_C}{\pi \cdot D}\right)^2 \cdot m_r / g - m_c - m_l\right)}{m_r} - d_1 \quad (3)$$

[0043] In view of equation (3), according to one variation the hoist drum control system 3 may hence be configured to determine the transversal resonance position, in addition to the payload and the hoist speed, based on the resonance frequency of the catenary 9a, the diameter D of the hoist drum 5, the frequency of an impulse in the rope occurring at cross-overs of the Lebus grooves, i.e. the rope kick frequency f_{exc} , the length of the vertical rope portion from a centre axis of the head sheave, i.e. head sheave axis A, to the mine shaft opening 13, i.e. the first distance d_1 , the length of the catenary, the weight of the conveyance m_c , and the rope weight per length unit m_r .

[0044] A method of controlling transversal resonance in the catenary 9a of the mine drum hoist system 1 by means of the hoist drum control system 3 will now be described with reference to Fig. 4.

[0045] In a step a) a current payload m_l of the conveyance 11 is determined by means of the processing system 3a of the hoist drum control system 3. The current payload may thus for example be determined in the manner described hereabove.

[0046] As has been previously mentioned, step a) may include receiving a first force measurement from the first load cell 7a of the head sheave 7 and a second force measurement from a second load cell 7b of the head sheave 7. In this case step a) involves determining a sum of force value by adding the first force measurement to the second force measurement, wherein the current payload is determined based on the sum of the force value F_{tot} . In particular, the current payload may be determined by subtracting the weight of the conveyance 11, the weight of the vertical rope portion 9b and the head sheave 7 from the sum of force value F_{tot} .

[0047] In a step b) a hoist speed v of the hoist drum 5 is obtained. The hoist speed v , which is proportional to the first speed of the conveyance 11, may be a proportional to a desired maximum speed of the conveyance, i.e. a pre-programmed parameter, or it may be determined in real-time.

[0048] It should be noted that it is not necessary for steps a) and b) to be performed in the above order; their order may be interchanged.

[0049] In a step c) a transversal resonance position, which is a certain second distance d_2 , along the vertical rope portion 9b is determined. The transversal resonance position is determined based on the current payload m_l and on the hoist speed v . The transversal resonance position may according to one variation be determined by means of equation (3). Alternatively the transversal resonance position may be retrieved from a look-up table in which a plurality of combinations of hoist speed and current payload are stored.

[0050] According to one variation in step c) the determining of the transversal resonance position is further based on a resonance frequency f_C of the catenary, a diameter d of the hoist drum 5, the frequency f_{exc} of an impulse in the rope 9 occurring at cross-overs of the Lebus grooves 5b, the length, i.e. the first distance d_1 , of the vertical rope portion 9b from a centre axis, i.e. head sheave axis A, of the head sheave 7 to a mine shaft opening 13, the weight of the conveyance m_c , the length of the catenary 9a and the rope weight m_r per length unit.

[0051] In a step d) the first speed of the conveyance 11 is reduced by the hoist drum control system 3 by reducing the hoist speed in a speed reduction zone which includes the transversal resonance position. The reduction of the first speed may thus for example be obtained by the hoist drum control system 3 controlling the drive unit 15, which in turn operates the motor M that drives the hoist drum 5.

[0052] The speed reduction zone may be determined by retrieving a speed reduction zone that has been determined for the transversal resonance position during a tuning/calibration procedure. The speed reduction zone may during the tuning procedure be determined based on catenary side force values F_C which are proportional to a difference between a first force measurement F_{La} measured by the first load cell 7a and the second force measurement F_{Lb} measured by the second load cell 7b. This procedure will be described in more detail in the following.

[0053] The tuning of the control procedure for the hoist drum control system 3 is of importance to be able to determine relevant transversal resonance positions, to thereby obtain efficient equipment, mineral and personnel transportation by means of the conveyance 11. Thus, prior to commissioning of the mine drum hoist system 1 and of the hoist drum control system 3, hoist drum control may be tuned or calibrated. The tuning procedure will be described in the following.

[0054] Turning to Fig. 3c, this illustration schematically shows a front view of the hoist drum 5, the head sheave 7, the first load cell 7a and the second load cell 7b. As may be seen in Fig. 3c, a fleet angle α between a vertical central axis defined by the head sheave and the catenary 9a is shown in two extreme positions. The fleet angle α depends on how much rope 9 has been uncoiled from the hoist drum 5, as the catenary moves between left and right along the axial direction of the hoist drum 5 during coiling operations.

[0055] According to one variation the hoist drum control system 3 is configured to determine a theoretical catenary side force value F_{C1} by determining the catenary component F_R , which is the rope pull, by means of the first force measurement F_{La} with the first load cell 7a and the second load measurement F_{Lb} the second load cell 7b, as has been described previously, and by multiplying the rope pull with sinus α , i.e. $F_R \cdot \sin(\alpha)$, where α is the fleet angle. The theoretical side force value F_{C1} , as shown for a number of second distances $d2$ is shown in the plot in Fig. 5a. The tuning procedure hence utilises first force measurements of the first load cell 7a and second force measurements of the second load cell 7b, measured along the entire mine shaft in which the conveyance 11 is to be transported vertically. It can be seen that the theoretical catenary side force value F_{C1} changes as the conveyance 11 moves along the vertical axis in the mine shaft, i.e. as the second distance $d2$ changes. In reality, the plot looks more like the example shown in Fig. 5b, where catenary oscillation forces due to transversal kicks which increase largely at resonance in the catenary 9a are superimposed onto the catenary side force value F_{C1} . A plot with catenary side force values F_C is thus obtained. Each area with increased catenary oscillations in a plot like then one shown in Fig. 5b corresponds to a transversal resonance position. Each catenary side force value F_C is proportional to the difference between the first force measurement F_{La} from the second force measurement F_{Lb} . The catenary side force values F_C may thus be determined based on the difference between the first force measurement F_{La} and the second force measurement F_{Lb} at each measurement point.

[0056] The magnitude of these catenary oscillation forces in the plot in Fig. 5b may be utilised by for example a commissioning engineer to determine whether a transversal resonance position is large enough to motivate a speed reduction of the conveyance and thus whether to determine a speed reduction zone around such a transversal resonance position. The commissioning engineer may for example calculate the difference between the maximum and minimum of a number of values over a period of time for this purpose. By means of studying the area in which a transversal resonance position occurs, the speed reduction zone may also be determined, i.e. how far before a transversal resonance position and how far after a transversal resonance position a speed reduction zone is to be defined. The speed reduction zone may for example in a first step be determined or obtained by a qualified guess by the commissioning engineer when studying a plot like then one presented in Fig. 5b. The conveyance 11 may afterwards be subjected to a test drive utilising the determined speed reduction zone. The catenary side force values F_C are then once again determined by means of the proportionality to the difference between the first force measurement F_{La} and the second force measurement F_{Lb} at each measurement point. It can then be verified whether the determined/guessed speed reduction zone is sufficient for reducing or eliminating the catenary oscillations at a transversal resonance position, or whether the speed reduction zone must be modified. This procedure may be repeated/iterated until a satisfactory result has been obtained. A thus determined speed reduction zone for a plurality of transversal resonance positions may then be stored by the hoist drum control system 3. Thus, when the hoist drum control system 3 at a later time, for the purpose of controlling transversal resonance in the catenary 9a, as described above, determines a transversal resonance position for a certain payload, the hoist drum control system 3 may be configured to determine the speed reduction zone for that transversal resonance position by retrieving a suitable speed reduction zone for that transversal resonance position during tuning/calibration.

[0057] Furthermore, the second speed, i.e. the reduced speed may also be determined by the commissioning engineer. The method of controlling transversal resonance in a catenary 9a may thus be tuned/calibrated.

[0058] Fig. 5c shows a plot in which the values in Fig. 5a have been subtracted from the measurement values in Fig. 5b, i.e. $F_{C2} = F_C - F_{C1}$, to obtain an adjusted catenary side force values F_{C2} . The adjusted catenary side force values F_{C2} provide better supervision of the tuning since the graph extends parallel to the x-axis. The maximum and minimum limits can in a simpler manner be defined and supervised. According to one variation, the hoist drum control system 3 is configured to determine the difference between the maximum and minimum of a number of values over a period of time of the catenary side force values F_C or the adjusted catenary side force values F_{C2} .

[0059] The inventive concept has mainly been described above with reference to a few examples. However, as is readily appreciated by a person skilled in the art, other embodiments than the ones disclosed above are equally possible

within the scope of the inventive concept, as defined by the appended claims.

Claims

1. A method of controlling transversal resonance in a catenary (9a) of a mine drum hoist system (1) comprising a hoist drum (5) having Lebus grooves (5b), a head sheave (7), a rope (9) having a catenary (9a) extending between the hoist drum (5) and the head sheave (7) and a vertical rope portion (9b), and a conveyance (11) attached to the vertical rope portion (9b), wherein the method comprises:
 - a) determining a current payload of the conveyance (11),
 - b) obtaining a hoist speed of the hoist drum (5), corresponding to a first speed of the conveyance (11),
 - c) determining a transversal resonance position along the vertical rope portion (9b) at which transversal resonance is generated in the catenary (9a) when reached by the conveyance (11) with the current payload and first speed, wherein the transversal resonance position is determined based on the current payload and on the hoist speed, and
 - d) reducing the first speed of the conveyance (11) in a speed reduction zone which includes the transversal resonance position.
2. The method as claimed in claim 1, comprising receiving a first force measurement (F_{La}) from a first load cell (7a) of the head sheave (7) and a second force measurement (F_{Lb}) from a second load cell (7b) of the head sheave (7), wherein step a) involves determining a sum of force value by adding the first force measurement to the second force measurement, wherein the current payload is determined based on the sum of force value.
3. The method as claimed in claim 2, wherein the current payload is determined by subtracting the weight of the vertical rope portion (9b), the weight of the conveyance (11) and the weight of the head sheave (7) from the sum of force value.
4. The method as claimed in any of the preceding claims, wherein in step c) the determining of the transversal resonance position is further based on a resonance frequency of the catenary (9a), a diameter (D) of the hoist drum (5), a frequency of an impulse in the rope (9) occurring at cross-overs of the Lebus grooves (9b), a length of the vertical rope portion (9b) from a centre axis (A) of the head sheave (7) to a mine shaft opening (13), a weight of the conveyance (11), a rope weight per length unit, and the length of the catenary (9a).
5. The method as claimed in any of claims 1-3, wherein in step c) the transversal resonance position is obtained from a look-up table which contains pre-calculated transversal resonance positions for a plurality of different current payloads and hoist speed combinations.
6. The method as claimed in any of the preceding claims, wherein step d) of reducing the first speed of the conveyance (11) involves reducing the hoist speed.
7. The method as claimed in any of the preceding claims, comprising determining the speed reduction zone based on the hoist speed obtained in step b), wherein the determining of the speed reduction zone involves retrieving a speed reduction zone that has been determined for the transversal resonance position and which has been determined based on catenary side force values (F_C) which are proportional to a difference between a first force measurement (F_{La}) measured by a first load cell (7a) and a second force measurement (F_{Lb}) measured by a second load cell (7b).
8. A computer program product comprising computer-executable components which when executed by a processing system (3a) causes a hoist drum control system (3) including the processing system (3a) to perform the method as claimed in any of claims 1-8.
9. A hoist drum control system (3) configured to control transversal resonance in a catenary of a mine drum hoist system (1), wherein the hoist drum control system (3) comprises:
 - a storage unit (3b), and
 - a processing system (3a),
 wherein the storage unit (3b) comprises computer-executable components which when executed by the processing system (3a) causes the hoist drum control system (3) to:

determine a current payload of a conveyance (11),
 obtain a hoist speed of a hoist drum (5), corresponding to a first speed of the conveyance (11),
 determine a transversal resonance position along a vertical rope portion (9b) of a rope (9) to which the
 conveyance (11) is attached, at which transversal resonance position transversal resonance is generated
 in the catenary (9b) when reached by the conveyance (11) with the current payload and first speed, wherein
 the transversal resonance position is determined based on the current payload and on the hoist speed, and
 reduce the first speed of the conveyance (11) in a speed reduction zone which includes the transversal
 resonance position.

10. A hoist drum control system (3) as claimed in claim 10, wherein the processing system (3a) is configured to receive
 a first force measurement (F_{La}) from a first load cell (7a) of a head sheave (7) and a second force measurement
 (F_{Lb}) from a second load cell (7b) of the head sheave (7), wherein the processing system (3a) is configured to
 determine a sum of force value by adding the first force measurement to the second force measurement, and wherein
 the processing system (3a) is configured to determine the current payload based on the sum of force value.

11. The hoist drum control system (3) as claimed in claim 9, wherein the processing system (3a) is configured to
 determine the current payload is by subtracting the weight of the vertical rope portion (9b), the weight of the con-
 veyance (11) and the weight of the head sheave (7) from the sum of force value.

12. The hoist drum control system (3) as claimed in any of claims 9-11, wherein the processing system (3a) is configured
 to determine the transversal resonance position based on a resonance frequency of the catenary (9a), a diameter
 (D) of the hoist drum, a frequency of an impulse in the rope occurring at cross-overs of Lebus grooves of a hoist
 drum, a length of the vertical rope portion (9b) from a centre axis (A) of the head sheave (7) to a mine shaft opening
 (13), a weight of the conveyance (11), a rope weight per length unit, and the length of the catenary (9a).

13. The hoist drum control system (3) as claimed in any of claims 10-12, wherein the processing system (3a) is configured
 to obtain the transversal resonance position from a look-up table which contains pre-calculated transversal resonance
 positions for a plurality of different current payloads and hoist speed combinations.

14. The hoist drum control system (3) as claimed in any of claims 10-13, wherein the processing system (3a) is configured
 to determine the speed reduction zone based on the hoist speed, wherein the processing system (3a) is configured
 to determine the speed reduction zone by retrieving a speed reduction zone that has been determined for the
 transversal resonance position and which has been determined based on catenary side force values which are
 proportional to a difference between a first force measurement measured by a first load cell and a second force
 measurement measured by a second load cell.

15. A mine drum hoist system (1) comprising:

a hoist drum (5) having Lebus grooves (5b),
 a head sheave (7),
 a rope (9) arranged to extend between the hoist drum (5) and the head sheave (7) to thereby define a catenary
 (9a) and a vertical rope portion (9b),
 a conveyance (11) arranged to be attached to the vertical rope portion (9b),
 a motor (M) arranged to operate the hoist drum (5), and
 a hoist drum control system (3) according to any of claims 10-14, arranged to control the motor (M).

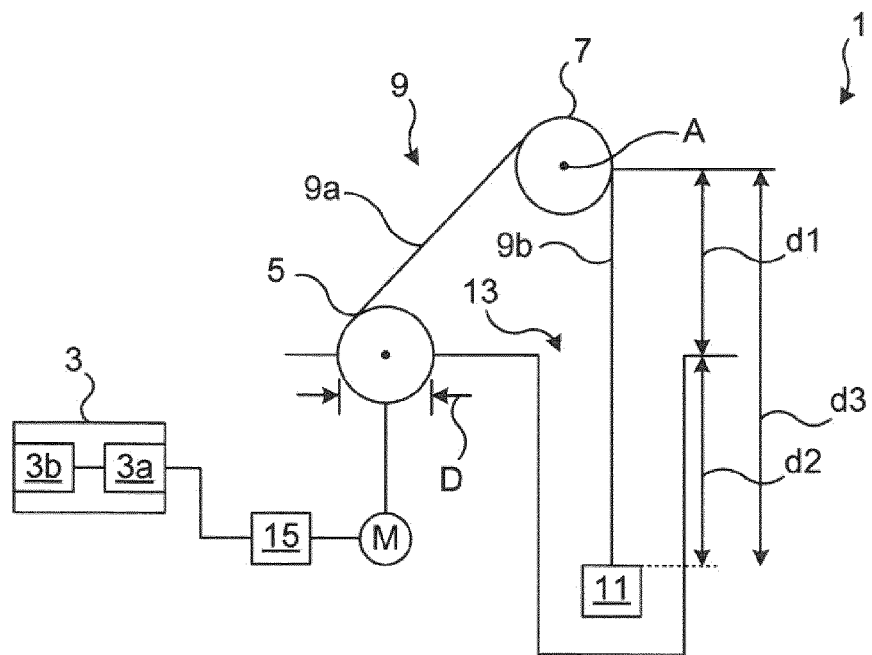


Fig. 1

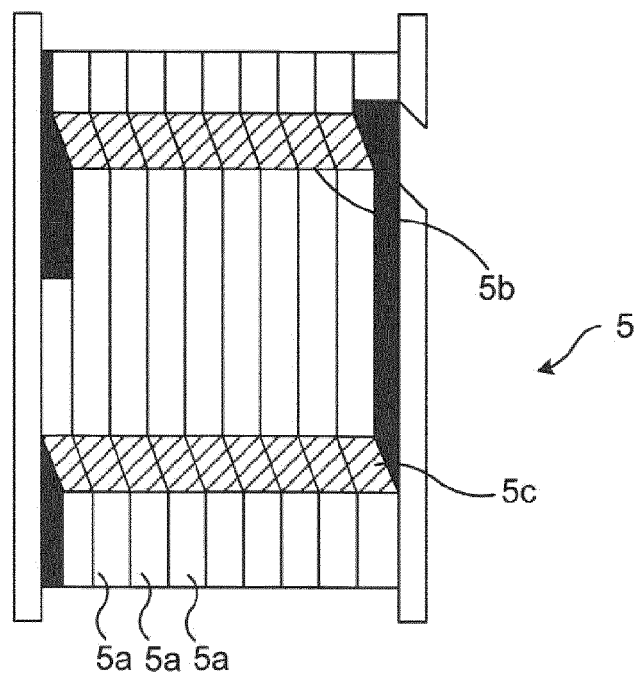


Fig. 2

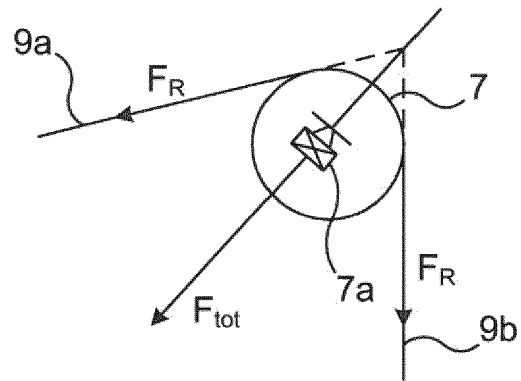


Fig. 3a

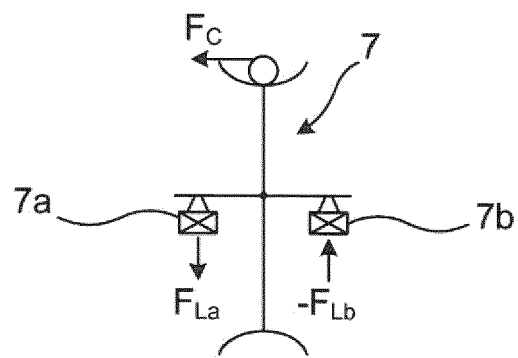


Fig. 3b

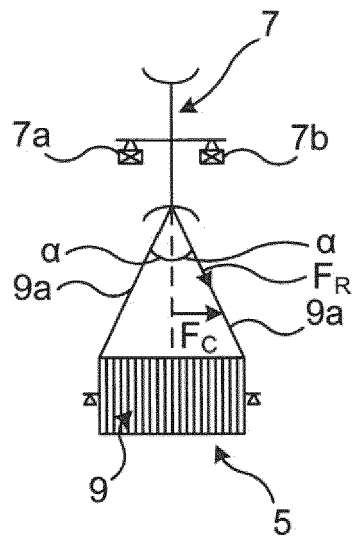


Fig. 3c

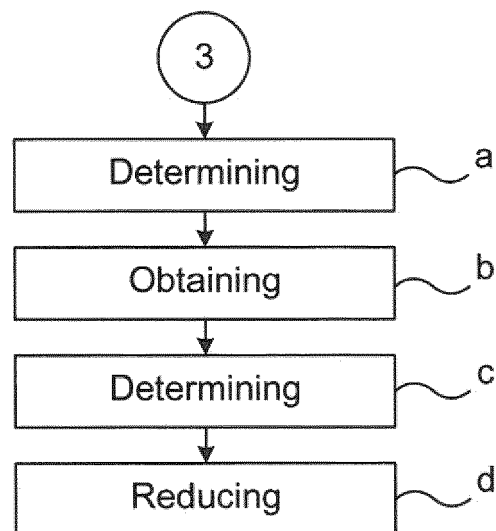


Fig. 4

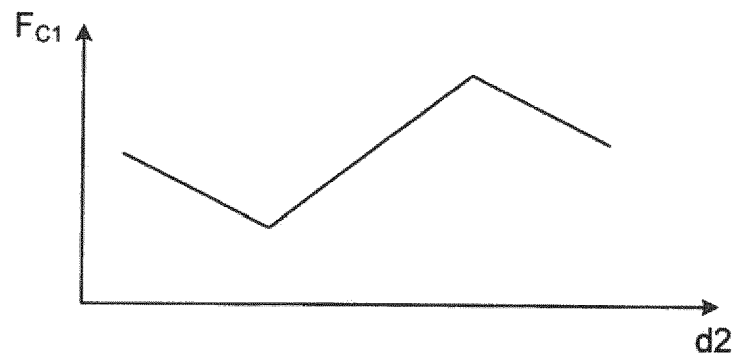


Fig. 5a

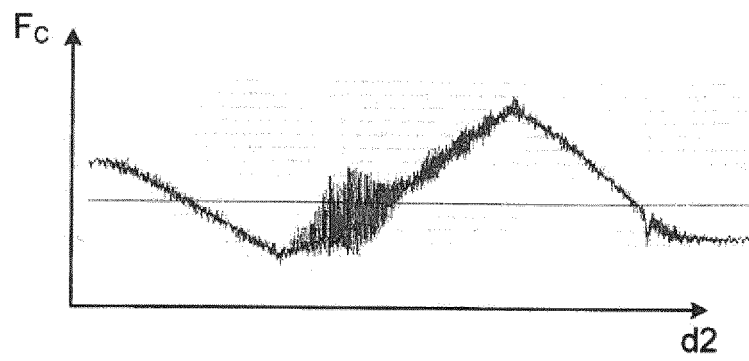


Fig. 5b

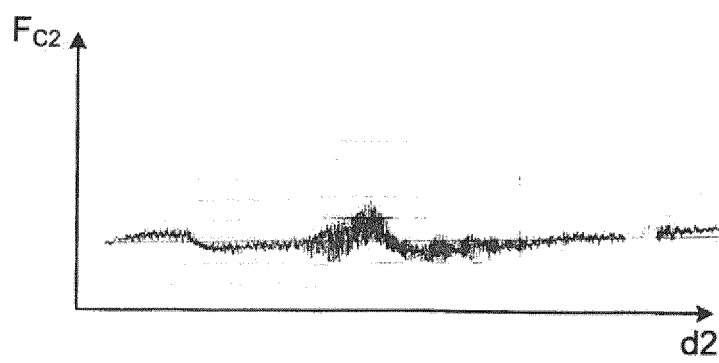


Fig. 5c



EUROPEAN SEARCH REPORT

Application Number
EP 15 15 1282

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	JP 2013 124176 A (PANASONIC CORP) 24 June 2013 (2013-06-24) * abstract; figures 1-7 *	1-15	INV. B66B19/00
A	BE 796 461 A1 (INST GEOTEKHNICHESKOI MEK AKAD; KH G UNI IM A M GORKOGO) 10 September 1973 (1973-09-10) * the whole document *	1-15	
A	CN 1 063 727 C (ASEA BROWN BOVERI [SE] ABB CO LTD [SE]) 28 March 2001 (2001-03-28) * abstract *	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			B66B B66D
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 11 June 2015	Examiner Lenoir, Xavier
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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ON EUROPEAN PATENT APPLICATION NO.**

EP 15 15 1282

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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11-06-2015

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2013124176 A	24-06-2013	NONE	
BE 796461 A1	10-09-1973	NONE	
CN 1063727 C	28-03-2001	CA 2168167 A1	31-07-1996
		CN 1138552 A	25-12-1996
		ZA 9600614 A	15-08-1996

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82