(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 December 2008 (04.12.2008)

PCT

(10) International Publication Number
WO 2008/145122 A1

(51) International Patent Classification:
E04B 1/98 (2006.01) *F16F 7/10* (2006.01)
F03D 11/04 (2006.01) *F16F 15/02* (2006.01)

(21) International Application Number: PCT/DK2007/050064

(22) International Filing Date: 31 May 2007 (31.05.2007)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant *(for all designated States except US)*: **Vestas Wind Systems A/S** [DK/DK]; Alsvej 21, DK-8940 Randers SV (DK).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **SLOTH, ERIK** [DK/DK]; Herningvej 270, DK-9220 Aalborg Ø (DK).

(74) Agent: **Plougmann & Vingtoft a/s**; Sundkrogsgade 9, Post Office Box 831, DK-2100 Copenhagen Ø (DK).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

(54) Title: A SYSTEM FOR DAMPING OSCILLATIONS IN A STRUCTURE

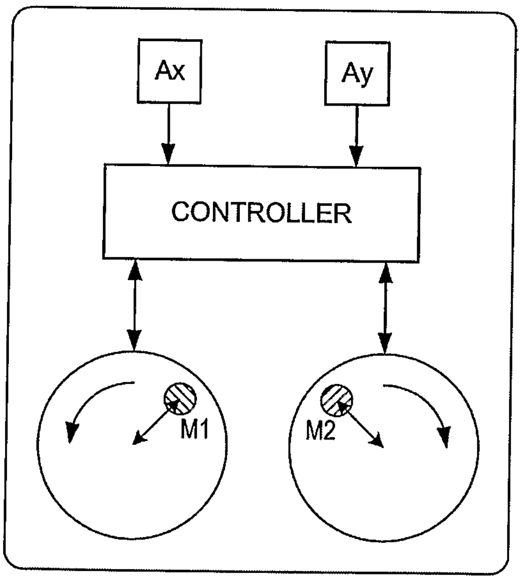

Fig. 1

(57) Abstract: The system for damping oscillations in a structure according to the invention provides two masses that can be controlled to rotate at the frequency of oscillation of the structure and in opposite directions about axes of rotation transverse to the direction of the oscillations. The masses have individually controllable moments of inertia, and when their moments of inertia are equal a harmonic linear force is generated. The phases of the rotating masses can be individually controlled whereby the direction of the resulting harmonic linear force can be controlled. The moments of inertia can be controlled by shifting their centres of gravity relative to the respective axes of rotation.

WO 2008/145122 A1

A SYSTEM FOR DAMPING OSCILLATIONS IN A STRUCTURE

FIELD OF THE INVENTION

This invention relates to damping oscillations in stationary structures, e.g. vertical tower-like structures such as wind turbine towers, chimneys, crane towers and building structures, but also horizontal structures such as bridges and crane arms, and also in moving structures such as wind turbine blades.

BACKGROUND OF THE INVENTION

For several reasons it may be desirable to dampen oscillations in such structures. Oscillations cause mechanical stress in the structures which may ultimately damage the structure itself. Human beings may experience discomfort when subjected to oscillations and equipment that is subject to oscillations may be caused to malfunction or even be damaged by oscillations.

JP 2001 020850 A and US 5 233 797 both disclose a system for damping one-dimensional oscillations in wind turbine towers. A movable mass is set into simple linear oscillations.

SUMMARY OF THE INVENTION

The system for damping oscillations in a structure according to the invention provides two masses that can be controlled to rotate at the frequency of oscillation of the structure and in opposite directions about axes of rotation transverse to the direction of the oscillations. When two masses of equal moments of inertia are rotated at the same frequency in opposite directions, the resulting equivalent force will be a harmonic force. The phases of the rotating masses can be individually controlled whereby the direction of the resulting linear harmonic motion can be controlled. The masses have individually controllable moments of inertia, and the moments of inertia can be controlled e.g. by shifting their centres of gravity relative to the respective axes of rotation. Thus by properly controlling the frequency, the amplitude and the phases of the rotating masses the resulting oscillations of the structure can be damped.

When the oscillating structure is a wind turbine tower the direction of the oscillation will often be in the axial direction of the rotor or in a relatively narrow interval around the axial direction such as up to about ±30 degrees. Under that assumption detection of the direction of the oscillation may be dispensed with, and the system for damping the oscillations can be mounted e.g. in the nacelle or in a fixed angle relative to the nacelle to be rotated together with the nacelle so as to dampen the oscillations in the axial direction.

The system may have means for detecting the direction of the oscillation such as a pair of accelerometers or other oscillation sensors. The absolute and relative phases of the moments of inertia can then be controlled so that the resulting combined motion of the rotating masses is in the detected direction of the oscillation. When used in a wind turbine tower the system of the invention may then be mounted at a fixed position in or at the tower.

The direction of the resulting combined motion of the rotating masses can be controlled by adjusting the angular position of the entire system or at least of the rotating masses treated as a unit, or by adjusting the absolute and relative phases of the rotating masses.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 shows schematically a system for damping oscillations in a structure according to the invention, and

Figure 2 illustrates a wind turbine tower with the system in figure 1 fixed thereto.

DETAILED DESCRIPTION OF THE INVENTION

The system in figure 1 comprises two oscillation sensors such as accelerometers Ax and Ay for sensing oscillations in perpendicular horizontal directions, the X direction and the Y direction. The skilled person will know how to use other types of oscillation sensors such as velocity sensors and displacement sensors and make appropriate changes. Signals representing the sensed accelerations in the X and Y directions are input to a controller where the input signals are processed to determine relevant properties of the sensed oscillation. Such properties include e.g. one or more frequencies of oscillation and also the corresponding amplitudes and phases in order to determine the direction of the oscillation in the plane determined by the X and Y directions at the individual frequencies. Typical frequencies to be damped are the fundamental frequency of the structure and its harmonics.

For each particular frequency to be damped, its actual frequency, amplitude and direction are measured. Then the controller calculates moments of inertia of the two masses appropriate for counteracting the oscillation. The individual phases of the rotation of the masses at the measured frequency are calculated so that the direction of the resulting equivalent linear harmonic motion is the same as the direction of the oscillation to be damped.

The moments of inertia can be varied in several ways. For example the two masses M1 and M2 can be solid masses that can be moved to different distances from the respective axes of rotation, or the masses can be a substance such as a liquid or a granular solid substance that can be pumped and distributed in separate chambers or compartments. By moving the masses or changing their radial distributions their moments of inertia can be controlled to the desired calculated values.

The two masses are set into rotation at the measured frequency of oscillation to be damped. The motors used for rotating the masses can be controlled to rotate at a desired frequency and phase.

Stepper motors are particularly useful for individually controlling the phases of the rotating masses M1 and M2. When the two masses are of equal moments of inertia and are rotated at the same frequency in opposite directions, the resulting equivalent motion will be a linear harmonic motion. By changing the phase of one or both masses the direction of the resulting equivalent linear harmonic motion will change correspondingly. Hereby the direction of the resulting equivalent linear harmonic motion can be controlled. Alternatively the angle of the assembly including the two rotating masses relative to the structure can be adjusted to obtain the desired direction of the resulting equivalent linear harmonic motion.

Two masses of equal moments of inertia will result in an equivalent linear harmonic motion when rotated in opposite directions at the same frequency. This is useful for damping linear oscillations. Two masses of unequal moments of inertia will result in an equivalent elliptical harmonic motion when rotated in opposite directions at the same frequency. This is useful for damping elliptical oscillations.

The first calculation of adjusting the moments of inertia and the phases may not immediately give a perfect damping of the oscillations. Therefore, the oscillation damping process is a continuous and adaptive process where the effect of a correction can be observed immediately. The residual oscillation is constantly measured, and if the residual oscillation is within acceptable limits no change is made to the moments of inertia and their phases. If and when the residual oscillation exceeds acceptable limits the moments of inertia and the phases of the rotating masses are recalculated and changed accordingly. Further, the oscillations are likely to change with time, and therefore the oscillations are measured continuously.

In figure 2 is illustrated a wind turbine tower with a nacelle on top of the tower. The above-described system is shown mounted inside the tower. The system can be produced as a unit for retrofitting into existing wind turbine towers and other structures, or it can be installed in the tower from the beginning. The system can have its own controller as illustrated, or control can be performed by a controller in the wind turbine. The system can be mounted on a platform welded to a wall of the tower, preferably on the inside, or mounted to a flange joint joining two tower sections. The system should preferably be mounted at a position where the oscillations are largest. Thus, for damping first order oscillations the system should be mounted near the top of the tower, and for damping second order oscillations the system should be mounted near the middle of the tower, i.e. at about half of the height of the tower.

In an alternative version the system can have a first pair of counter-rotating masses for damping oscillations in a first horizontal direction and a second pair of counter-rotating masses for damping oscillations in a second horizontal direction. Preferably the first and second directions are perpendicular to each other. Together the two pairs of counter-rotating masses are suitable for damping vibrations in any horizontal direction. Similarly, the system can be expanded with a third pair of counter-rotating masses for damping oscillations in the vertical direction.

In figure 1 the two rotating masses M1 and M2 are shown side by side with their axes of rotation parallel to each other. Alternatively they may be arranged coaxially one above the other whereby they take up less space in the direction transversal to the axis of rotation.

Claims:

1. A system for damping oscillations in a structure, the system comprising
   - means for determining the frequency and the amplitude of the oscillations in the structure,
   - a first mass (M1) rotatable in a first direction of rotation about a first axis of rotation transverse to the direction of the oscillations, the first mass having a first controllable moment of inertia about the first axis of rotation,
   - a second mass (M2) rotatable in a second direction of rotation opposite the first direction of rotation about a second axis of rotation, the second mass having a second controllable moment of inertia about the second axis of rotation,
   - means for securing the system to the structure, and
   - a controller for controlling the first and second moments of inertia and for controlling the first and second masses to rotate at the detected frequency and at respective phases such as to dampen the oscillations when the system is secured to the structure.

2. A system according to claim 1 further comprising means (Ax, Ay) for determining a direction of the oscillations in the structure.

3. A system according to claim 1 or 2 wherein the phase of both masses (M1, M2) can be controlled individually.

4. A system according to any one of claims 1 - 3 comprising stepper motors for rotating the masses (M1, M2).

5. A system according to claim 1 or 2 wherein the angle of the assembly of the two rotating masses relative to the structure can be adjusted.

6. A system according to any one of claims 1-5 wherein the second axis of rotation is parallel to the first axis of rotation.

7. A system according to any one of claims 1-6 comprising a first pair of masses for damping oscillations in a first direction and a second pair of masses for damping oscillations in a second direction.

8. A structure that can undergo oscillations and including a system according to any one of claims 1-7 mounted at a position where the oscillations to be damped are largest.

9. A structure according to claim 8 wherein the structure is a wind turbine tower.

10. A structure according to claim 9 wherein the system is welded to a wall of the tower.

11. A structure according to claim 9 wherein the system is mounted to a flange joint joining two tower sections.

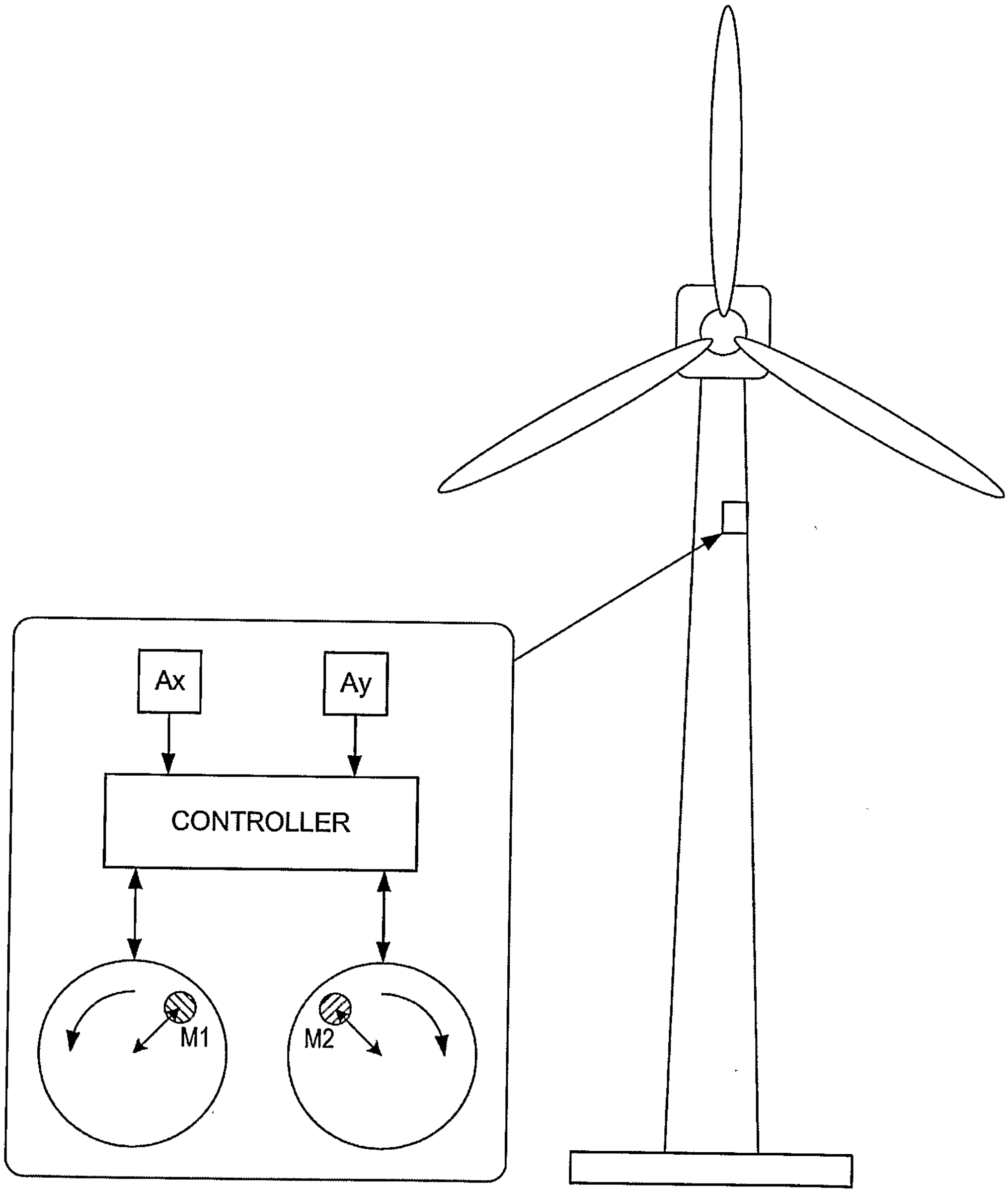

Fig. 1

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2007/050064

A. CLASSIFICATION OF SUBJECT MATTER
INV. E04B1/98 F03D11/04 F16F7/10 F16F15/02

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F16F E04B F03D

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/077845 A1 (OLGAC NEJAT [US] ET AL) 14 April 2005 (2005-04-14) paragraph [0015]; claim 1; figures 1a,6 paragraph [0038] - paragraph [0043]	1-8
Y	paragraph [0099] - paragraph [0101]	9-11
Y	EP 0 853 197 A (AERPAC UK LTD [GB]) 15 July 1998 (1998-07-15) figures 3-5	9-11
X	WO 96/06290 A (SMIDTH & CO AS F L [DK]; MADSEN JOHN GRAM [DK]) 29 February 1996 (1996-02-29) the whole document	1

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 February 2008	21/02/2008

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Hytrowski, Pascal

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2007/050064

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 95/02133 A (SMIDTH & CO AS F L [DK]; MADSEN JOHN GRAM [DK]) 19 January 1995 (1995-01-19) the whole document	1
X	EP 0 409 462 A (WRIGHT BARRY CORP [US]) 23 January 1991 (1991-01-23) the whole document	1
X	JP 60 237239 A (MITSUBISHI HEAVY IND LTD) 26 November 1985 (1985-11-26) abstract	1
A	DE 42 19 648 A1 (KLEIN ALB GMBH CO KG [DE]) 14 January 1993 (1993-01-14) abstract	1
A	WO 88/06687 A (SMIDTH & CO AS F L [DK]) 7 September 1988 (1988-09-07) abstract	1
A	US 2005/075210 A1 (FREDERICKSON KIRK CHARLES [US]) 7 April 2005 (2005-04-07) figure 8	1
A	FR 2 858 034 A (CF GOMMA SPA [IT]) 28 January 2005 (2005-01-28) abstract	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/DK2007/050064

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2005077845	A1	14-04-2005	NONE			
EP 0853197	A	15-07-1998	NL	1005000	C2	15-07-1998
WO 9606290	A	29-02-1996	AU	3341395	A	14-03-1996
			CN	1156498	A	06-08-1997
			DE	69502200	D1	28-05-1998
			DE	69502200	T2	13-08-1998
			DK	0776431	T3	18-01-1999
			EP	0776431	A1	04-06-1997
			ES	2115394	T3	16-06-1998
			JP	10504633	T	06-05-1998
WO 9502133	A	19-01-1995	AU	7122394	A	06-02-1995
			CN	1127030	A	17-07-1996
			DE	69403079	D1	12-06-1997
			DE	69403079	T2	14-08-1997
			DK	119193	A	10-01-1995
			EP	0706621	A1	17-04-1996
			ES	2101546	T3	01-07-1997
			JP	3475404	B2	08-12-2003
			JP	8512386	T	24-12-1996
EP 0409462	A	23-01-1991	CA	2020801	A1	15-01-1991
			DE	69008633	D1	09-06-1994
			DE	69008633	T2	24-11-1994
			JP	3149430	A	26-06-1991
			US	5005439	A	09-04-1991
JP 60237239	A	26-11-1985	NONE			
DE 4219648	A1	14-01-1993	NONE			
WO 8806687	A	07-09-1988	AU	1396088	A	26-09-1988
			DK	107487	A	03-09-1988
			YU	41988	A1	31-10-1990
US 2005075210	A1	07-04-2005	WO	2005033544	A2	14-04-2005
FR 2858034	A	28-01-2005	NONE			