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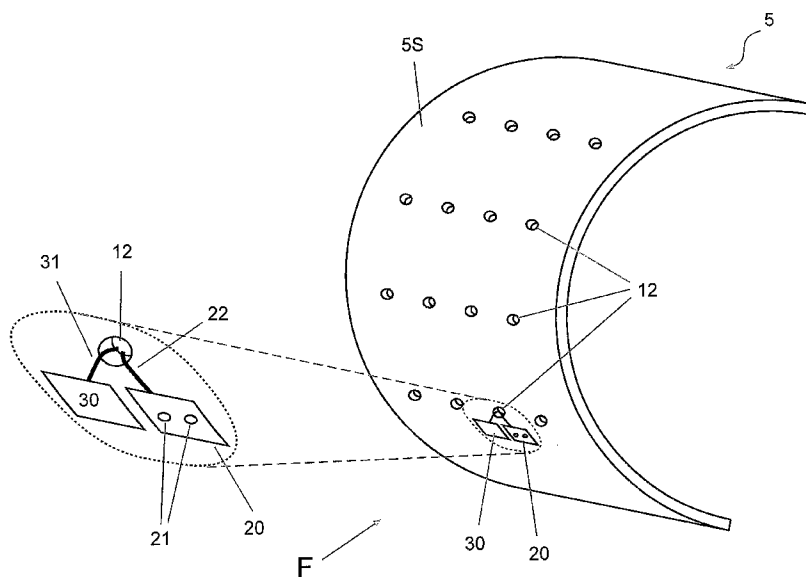
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(54) Title: METHOD AND SYSTEM FOR DETECTING THE RISK OF ICING ON AERODYNAMIC SURFACES



(57) Abstract: The invention relates to a method and a system for detecting the risk of icing on aerodynamic surfaces lapped by a fluid flow (F), in particular on load-bearing surfaces of fluid machines, of the type comprising a temperature sensor (20). The system is characterized in that the temperature sensor (20) is located close to the aerodynamic surface (5S) to be monitored for detecting the temperature of the surface (5S), and that the system comprises a rain sensor (30) located close to the surface (5S) for detecting the presence of water on said surface (5S). The system can thus detect the risk of icing on aerodynamic surfaces in a very effective, simple and inexpensive manner.

METHOD AND SYSTEM FOR DETECTING THE RISK OF ICING ON AERODYNAMIC SURFACES

DESCRIPTION

The present invention relates to a method for detecting and signalling the risk of icing on aerodynamic surfaces, in particular on load-bearing surfaces of fluid machines, e.g. rotor blades of Wind Energy Converting Systems (WECS).

5 The invention mainly applies to the WECS field, wherein no solution has yet been found to the problem of forecasting the occurrence of conditions leading to icing on the blades of a wind turbine. This forecast is used for two main purposes, i.e. for detecting icing conditions and stopping the wind turbine, or for activating and deactivating an anti-icing and de-icing system installed on the turbine.

10 In the aircraft field, a solution has been found for detecting icing conditions by using Rosemount® type sensors. Such a sensor is a small metal cylinder to be exposed to actual atmospheric conditions, which gets covered with ice when icing conditions exist, thus changing its vibration frequency and signalling that icing is occurring. The sensor is installed directly on the wing and is hit by the fluid flow directed against it, so that it provides an accurate indication of the actual icing conditions of the
15 monitored surface.

The same sensor, when used on blades of wind turbines, causes considerable rotor unbalance problems due to the mass of the sensor itself. When installed on fixed surfaces of WECS, e.g. on the nacelle of a wind turbine, it provides unreliable indications about the actual icing occurring on the rotor blades, due to the difference
20 existing between the relative speed of the flow lapping the different sections of the blade and the absolute speed of the wind, detected in a fixed location. In practice, the sensor installed on the nacelle may indicate no icing, while serious icing is occurring on the blade. Also, when the ice sensor begins to send the icing signal, the rotor may already be in heavy icing conditions. The above remarks about the Rosemount® type
25 sensor also apply, in general, to any known sensor capable of measuring icing directly on fixed surfaces of a WECS.

Known systems adopt a strategy for detecting the presence or risk of icing which is based on the detection of machine parameters and atmospheric conditions. For example, they measure either tower vibrations and ambient temperature or power output and ambient temperature, as shown in patent documents US 2005/276.696 and US 6.890.152. The logic of such strategies is to deduce the occurrence of the icing phenomenon by detecting an anomalous behaviour of the wind turbine, such as too much vibration or a power output drop, at the same time verifying environmental parameters, e.g. checking that ambient temperature is below 0° C.

The above-mentioned known systems have the main drawback consisting of being unreliable in effectively forecasting and detecting the presence of ice, as soon as the icing phenomenon occurs. As a matter of fact, when icing is detected the phenomenon may already be so advanced as to require the wind turbine to be stopped in order to prevent it from being damaged; or else conditions may arise when there is only a remote risk of icing, but the system signals that icing is about to occur. For example, when turbulent events or strong wind changes (which are typical of mountain areas) bring about anomalous vibration phenomena and a temperature below 0° C is detected, the system will stop the turbine even though no icing conditions exist, since the operating environment is not sufficiently humid.

According to documents US 5.005.015 and EP 1.466.827, sensors for detecting the presence of water or ice are also known to be applied directly to aerodynamic surfaces, in particular to engine blades. These systems can only detect the presence or the thickness of water or ice possibly being present on the surfaces, but they cannot forecast future icing.

The present invention aims at solving the above-mentioned prior art drawbacks by providing a method for detecting the risk of icing on aerodynamic surfaces which can actually and effectively forecast the occurrence of water icing conditions on aerodynamic surfaces, in particular on the blades of a wind turbine. The invention also comprises a system for implementing said method.

It is an object of the present invention to provide a system which is simple, inexpensive and absolutely effective whatever the operating conditions of the aerodynamic surfaces on which the risk of icing is to be detected.

According to the present invention, said objects are achieved through a method and

a system for detecting the risk of icing on aerodynamic surfaces having the features as set out in the appended claims.

The system comprises a temperature sensor and a sensor for detecting the presence of water or ice, which are installed in the immediate vicinity of the aerodynamic surface on which the risk of icing is to be detected, in order to detect both the temperature and the presence of water on the same surface. Therefore, the sensing portions of the respective sensors are installed in such a way that the actual conditions of the monitored aerodynamic surface can be detected.

The detection of temperature and of the presence of water obtained directly on the concerned surface allows to monitor the risk of icing in an effective manner. For example, when the presence of drops of water is detected together with a temperature below a preset critical temperature, i.e. a temperature at which the risk of impending icing is to be signalled (e.g. 3° C), the system according to the invention can signal an actual danger of icing.

The system according to the invention can also verify empirically whether, in combination with the actual surface temperature, water drops are really forming on said surface, thus determining whether the risk of icing is real or not. For example, if there is a temperature between -1° and 1° C and there is no water on the monitored surface, the system according to the invention can abstain from signalling the risk of icing, as indeed is the case when air humidity is very low.

Advantageously, the sensors are arranged on the aerodynamic surface to be monitored in positions corresponding to or surrounding the areas of maximum pressure of the fluid flow, i.e. those areas of the aerodynamic surface where the risk of icing is highest. For example, such a position may be the leading edge of a wing or a rotor blade surface.

Furthermore, the sensors are arranged on the aerodynamic surface close to each other, so that homologous conditions of the fluid flow can be detected in very close locations. This greatly prevents wrong detections of the actual condition of the fluid flow hitting the surface in a certain point. From this point of view, the ideal solution is to use a sensor which includes the functions for detecting the presence of water or ice as well as the functions for measuring the temperature of a same small surface.

Further objects, features and advantages of the present invention will become

apparent from the following detailed description of an embodiment thereof, provided by way of non-limiting example with reference to the annexed Fig. 1, which is a perspective view of the system according to the invention applied to a section or keystone of a rotor blade.

5 In particular, the rotor blade section shown and designated by reference numeral 5 is of the type illustrated in document WO 2004/36038 in the name of the same Applicant of the present patent application. Said blade 5 is therefore provided with holes 12 on its outer surface 5S. Near the leading edge of the blade profile and of the hole 12, and on the outer surface of the blade 5S, there are a first weather sensor, in
10 this case a temperature sensor 20, and a second weather sensor, in this case a sensor for detecting the presence of water or ice 30, hereafter simply referred to as rain sensor. With reference to the direction of the fluid flow F lapping the blade 5, these sensors 20, 30 are located upstream of the hole 12, so that the respective readings are not affected by the fluid flow coming out of the hole.

15 The temperature sensor 20, e.g. a thermocouple, is a small, light unit of a known type, shaped as a thin plate and fitted with a sensing portion 21, which is installed in such a way as to intercept the fluid flow lapping the outer surface 5S. The sensor is located upstream of the hole 12, and is glued or otherwise secured to the outer surface 5S. On the rear side, it has an electric connection 22 running along the inner
20 surface of the blade 5 up to a data acquisition system (DAS), not shown for simplicity's sake.

The DAS is of a known type and advantageously arranged, for inertial purposes, outside the rotor blade, for example on the nacelle of the WECS, and the system according to the present invention includes known means for transmitting the
25 signals detected by the sensors to the DAS.

The rain sensor 30, of a type similar to those installed on automotive windshields, is also glued upstream of the hole 12 and fitted with a respective electric connection 31 running along the side walls of the hole and the inner surface of the blade 5 up to the
30 DAS. The sensors 20, 30 employed are known and, once installed on the outer surface 5S, their shapes and dimensions do not affect the flow F against said surface.

The DAS can process the information about the presence/absence of water sent by the rain sensor 30 and the surface temperature value detected by the temperature

sensor 20 so that, when drops of water are not detected on the surface, it will not signal the risk of icing. On the contrary, when the presence of water is detected together with a temperature below a preset critical value, e.g. 3° C, the DAS will signal the risk of icing or impending icing to a central control unit.

5 Advantageously, the low weight, the simplicity and the reliability of known rain sensors and temperature sensors allow them to be easily employed also on rotary blades of wind turbines, thus providing a system for detecting the risk of icing on aerodynamic surfaces which is simple, reliable and inexpensive.

10 Unlike the prior art, the system according to the invention performs a detection of a pair of physical parameters, in particular temperature and presence of water, directly on the surfaces concerned by the risk of icing, thus providing a timely and accurate measurement. Said parameters, after being processed by the DAS, allow to forecast the actual risk of icing in an effective manner. On the contrary, according to the prior art the risk of icing is essentially forecasted on the basis of parameters which are not
15 measured on the surface to be monitored, in that they are derived and processed by sensors often located far from the involved surfaces. Therefore, such measurements are in several instances wrong and do not represent actual surface conditions.

In short, the system for detecting the risk of icing on aerodynamic surfaces according to the invention allows to signal the risk of icing and possibly to activate an anti-icing
20 system very accurately and effectively, without risking that icing has already occurred on the concerned aerodynamic surfaces, thus keeping the monitored machine always in the best operating conditions.

It is clear that many changes may be made by the man skilled in the art to the system for detecting the risk of icing on aerodynamic surfaces, in particular on load-bearing
25 surfaces of fluid machines, according to the present invention; likewise, it is also clear that in the practical implementation of the invention, the details herein illustrated may have different shapes or be replaced with equivalent technical elements.

For example, if the system is applied to rotor blades without holes, suitable holes may be made for routing the electric connections of the sensors or for housing the
30 sensors themselves, which in any case are to be configured and installed so that the sensing portion thereof lies on the surface to be monitored.

Also, when relatively thick sensors are used, suitable openings may be obtained in

the blade for housing said sensors without affecting the fluid flow around the blade.

CLAIMS

1. Method for detecting the risk of icing on aerodynamic surfaces (5S) lapped by a fluid flow (F), such as load-bearing surfaces of fluid machines (5), comprising the steps of:
 - detecting the temperature near the aerodynamic surface (5S);
 - 5 - detecting the presence of water on the surface;
 - processing the data relating to temperature and presence of water, in order to check whether it corresponds to icing conditions or not.
2. Method according to claim 1, wherein the detection of temperature and presence of water provides signals which are processed by electronic means.
- 10 3. Method according to claims 1 or 2, wherein the aerodynamic surfaces (5S) are those of a wind turbine rotor.
4. System for implementing the method according to the preceding claims, characterized by comprising a temperature sensor (20) located close to the aerodynamic surface (5S) to be monitored for detecting the temperature of the surface (5S), and a rain sensor (30) located close to the surface (5S) for detecting the presence of water on the surface (5S).
- 15 5. System according to claim 4, wherein the sensors (20, 30) are arranged in positions corresponding to or surrounding the areas of maximum pressure of the aerodynamic surface (5S) to be monitored.
- 20 6. System according to claims 4 or 5, wherein the temperature sensor (20) has a sensing portion (21) located where the fluid flow (F) laps the aerodynamic surface (5S).
7. System according to any of claims 4 to 6, wherein the sensors (20, 30) are arranged on the aerodynamic surface (5S) close to each other.
- 25 8. System according to claim 7, wherein the sensors (20, 30) are of a type made up of small plates and are secured to the outer surface (5S).
9. System according to any of claims 4 to 8, wherein said temperature and rain sensors (20, 30) are built in a single sensor.
10. System according to any of claims 4 to 9, comprising a data acquisition system
- 30 connected to said sensors (20, 30), in particular through respective connection means

(22, 31), for processing the received signals in order to provide a "risk of icing" signal to be sent to a central control unit.

11. System according to claim 10, wherein when the sensors (20, 30) detect the presence of water and a temperature below a preset critical value, the data acquisition system signals the risk of icing or impending icing to a central control unit.

12. System according to any of claims 4 to 10, wherein said aerodynamic surface is the outer surface (5S) of a rotor blade (5) and the fluid machine is a wind turbine.

13. System according to claim 12, wherein the blade is of a holed type and the sensors (20, 30) are located upstream of a single hole (12) relative to the fluid flow (F) lapping the outer surface (5S) of the blade (5).

14. System according to claims 11 or 12 and 13, wherein the acquisition system is arranged on the nacelle of the wind turbine, the system comprising means for transmitting the signals detected by the sensors (20, 30) to the controller.

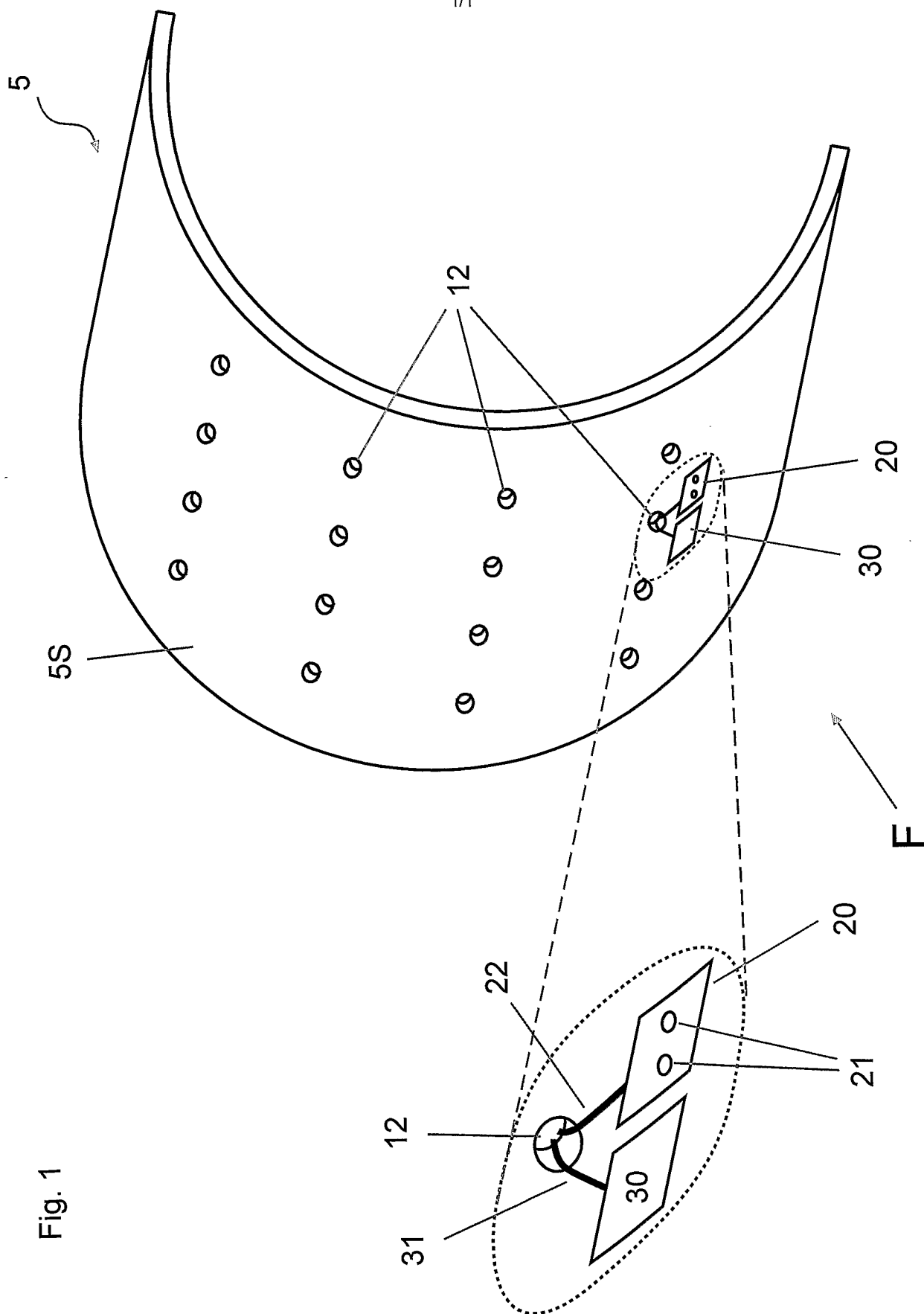


Fig. 1

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

INV. B64D15/20 F03D11/00 G08B19/02

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

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Minimum documentation searched (classification system followed by classification symbols)

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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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 657 349 A1 (LABKO ICE DETECTION OY [FI]) 14 June 1995 (1995-06-14)	1-10, 12-14
Y	page 2, lines 1-30 page 3, lines 30-50 page 4, line 25 - page 5, line 17 page 5, line 50 - page 7, line 3 page 7, lines 14-19 figures 1-3,7,8,10,11	11
Y	----- WO 2005/020175 A (BOEING CO [US]; COOK DONALD E [US]; FEIDER MICHAEL P [US]) 3 March 2005 (2005-03-03)	11
A	paragraphs [0001] - [0004] paragraphs [0012] - [0015] paragraphs [0019], [0020] figures 1,2 ----- -/--	1-10, 12-14



Further documents are listed in the continuation of Box C.



See patent family annex.

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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

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G document member of the same patent family

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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2007/001397

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 98/01340 A (LM GLASFIBER AS [DK]; GRABAU PETER [DK]) 15 January 1998 (1998-01-15) page 1, line 2 - page 2, line 9 page 2, line 36 - page 3, line 6 page 4, lines 17-25 figures 1,2 -----	1-14
A	EP 1 466 827 A (HUTH-FEHRE THOMAS DR [DE]) 13 October 2004 (2004-10-13) cited in the application the whole document -----	1-14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 0657349	A1	14-06-1995	AT 164136 T	15-04-1998
			CA 2137601 A1	10-06-1995
			DE 69409072 D1	23-04-1998
			FI 935504 A	10-06-1995
			JP 7239321 A	12-09-1995
			NO 944374 A	12-06-1995
			US 5585551 A	17-12-1996
WO 2005020175	A	03-03-2005	AU 2003302319 A1	10-03-2005
			CA 2535885 A1	03-03-2005
			CN 1820289 A	16-08-2006
			EP 1661100 A1	31-05-2006
			JP 2007521463 T	02-08-2007
WO 9801340	A	15-01-1998	AT 251570 T	15-10-2003
			AU 3255197 A	02-02-1998
			CA 2259975 A1	15-01-1998
			CN 1224394 A	28-07-1999
			DE 69725445 D1	13-11-2003
			DE 69725445 T2	05-08-2004
			DK 0914276 T3	08-12-2003
			EP 0914276 A1	12-05-1999
			NO 986179 A	23-02-1999
EP 1466827	A	13-10-2004	DE 10315676 A1	04-11-2004