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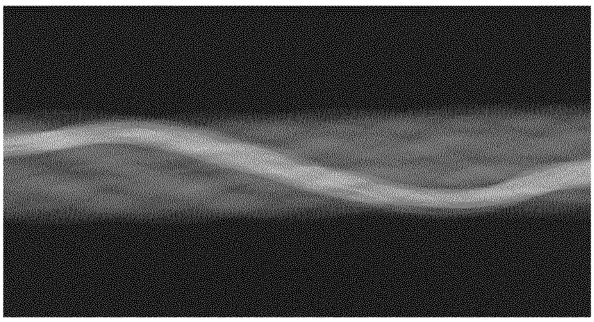
(54) Synthetic tracking fiber

(57) A tracking fiber for non-destructive testing of linear tension members wherein the tracking fiber comprises a fiber and a composition, wherein the fiber comprises a synthetic polymer and the composition comprises at least one component chosen from:
i) an alkali metal, an earth alkali metal, a metal chosen from cerium, neodymium, zinc, iron, zirconium, tantalum, silver, gold, platinum, titanium or iridium, a metal alloy and/or a derivative thereof,
ii) a halogen and/or derivative thereof, or
iii) an organic compound.

Also a linear tension member with said tracking fiber and the use of said tracking fiber for testing of a linear tension member, e.g. by X-ray, terahertz, electromagnetic, permanent magnetic filed analysis, NMR or electric conductivity is disclosed.

Fig. 2



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Description

[0001] During use, the mechanical properties of a linear tension member start to decrease after a certain period of time. In some applications, e.g., when the linear tension member is used as mooring line, the linear tension member suffers from tension-tension fatigue. That is, the linear tension member is subjected to a cyclic increase and decrease of tension, and this has been found to detrimentally affect the properties of the linear tension member. In other applications, e.g., where the linear tension member is used over pulleys, the linear tension member suffers from bending fatigue. That is, the properties of the linear tension member deteriorate when the linear tension member is subjected repeatedly to bending.

[0002] One of the key concerns of a linear tension member user is to determine when a linear tension member should be replaced. Replacing a linear tension member entails substantial costs and effort, however. Not only the costs of the new linear tension member need to be factored in, but also the costs associated with down-time of the unit wherein the linear tension member is used, and the labour costs associated with the replacement. Therefore, it is undesirable to replace a linear tension member too soon, that is, substantially before the end of its lifetime. On the other hand, the situation that a linear tension member breaks or otherwise fails is unacceptable, and needs to be prevented.

[0003] Therefore, within the linear tension member field methods have been developed to test the properties of the linear tension member while it is in use, to allow the linear tension member user to determine when the linear tension member should be replaced. Testing the properties of a linear tension member without disassembling or destroying the linear tension member, preferably while it is in use is indicated in the field as non-destructive testing.

[0004] While different non-destructive testing methods have shown their value in steel wire linear tension members, they are not directly applicable to synthetic linear tension members, as they rely on either the magnetic or electrically conductive properties of the linear tension member. Synthetic linear tension members are in principle very attractive to replace steel linear tension members in numerous applications, as they have a number of advantages, including lighter weight for the same strength, insensitivity to corrosion, and lower maintenance requirements. However, for synthetic linear tension members to be used in high risk applications, the availability of a method for testing the linear tension member properties in use is required.

[0005] Methods for non-destructive testing of synthetic linear tension members are known. US 6,886,666 describes the non-destructive testing of e.g. metallic tracking fibers in synthetic load bearing members. The load bearing member comprises a first, structural material (which can be a synthetic fiber) and at least one element of a second material (the tracking fiber or element). The second material is used for detecting localized strain on the load bearing member.

[0006] A number of documents describe that a tracking fiber of a different material is introduced into linear tension members to monitor their condition. EP0731209 describes the use of electroconductive carbon fibers as indicator fibers for synthetic linear tension members, while US5182779 discloses that a fiber optic is included in a linear tension member and changes in the fibers light's transmissive or reflective properties are used to assess the linear tension member condition. US6289742 describes how damages to the sheath of a linear tension member can be identified by including a breaking element (e.g. copper wire) on the outside of rope fibers or in the rope sheath.

[0007] The disadvantage of using a tracking or indicator fiber which is made from a completely different material than the load bearing fibers of the linear tension member is that the tracking fiber which is used to assess the condition of the linear tension member inherently possesses characteristics different from the structural material, i.e. the load bearing fibers.

[0008] To overcome this disadvantage for synthetic load bearing members a tracking fiber would be advantageous which comprises a synthetic fiber, possibly even of the same synthetic polymer as the load bearing fibers of the linear tension member, so as to have similar properties as the load bearing fibers, but which tracking fiber is nevertheless detectable with numerous techniques used in non-destructive testing.

[0009] The present invention provides such a tracking fiber. The present invention is directed to a tracking fiber for non-destructive testing of linear tension members characterized in that the tracking fiber comprises a fiber and a composition, wherein the fiber comprises a synthetic polymer and the composition comprises at least one component chosen from:

i) an alkali metal, an earth alkali metal, a metal chosen from cerium, neodymium, zinc, iron, zirconium, tantalum, silver, gold, platinum, titanium or iridium, a metal alloy and/or a derivative thereof,
ii) a halogen and/or derivative thereof, or
iii) an organic compound.

The invention is also directed to a linear tension member comprising such a tracking fiber.

[0010] The term tracking fiber indicates a fiber which is part of a linear tension member and is used to determine the condition of the linear tension member by non-destructive testing methods. The condition of the tracking fiber can be detected by at least one of the various non-destructive detection methods and the condition of the tracking fiber is used to determine the condition of the linear tension member. More specifically, the composition, even more specifically the component described in the present invention is detected by the non-destructive testing method, because the synthetic fiber part of the tracking fiber is less or not suited for non-destructive testing.

[0011] For the purpose of this invention linear tension members are defined as elongated objects of which one dimension is much larger than the other two dimensions. The linear tension member is especially fit to be subjected to axial tensile forces and therefore functions as load-bearing member.

[0012] Non-limiting examples of linear tension members are ropes, lines, tethers, mooring lines, tow lines and cables. Such linear tension members can be used in a variety of applications, e.g. in marine and mining environments.

[0013] The term fiber is used for the smallest individual element in the linear tension member, e.g. the synthetic polymer fiber or tape. Within the context of the present specification the term fiber refers to longitudinal elements the largest dimension of which, the length, is larger than the second smallest dimension, the width, and the smallest dimension, the thickness. More in particular, the ratio between the length and the width generally is at least 10. The maximum ratio is not critical to the present invention and will depend on the processing parameters of the fibers. Accordingly, the term fiber used in the present invention encompasses monofilaments, fibers comprised of multiple filaments (so-called multifilament fibers) but also tapes, strips, and other longitudinal elements having a regular or irregular cross-section.

[0014] In one embodiment the tracking fiber consists of the fiber and the composition.

In one embodiment the fiber consists of the synthetic polymer. In one embodiment the tracking fiber consists of the synthetic polymer fiber and the composition.

[0015] The synthetic polymer of the fiber can be chosen from aramid, polyethylene, polyamide, polyester, liquid crystal polymers (e.g. polyarylates), polypropylene, polybenzazole, polyacrylonitril and carbon fibers resulting thereof.

[0016] In one embodiment, aramid fibers are used, i.e. para-aramid or meta-aramid fibers, preferably para-aramid fibers. Meta-aramid is shorthand for meta-linked aromatic polyamides, such as poly (m-phenylene isophthalamide). Para-aramid is shorthand for para-oriented aromatic polyamides which are condensation polymers of a para-oriented aromatic diamine and a para-oriented aromatic dicarboxylic acid halide. As typical paraaramids are mentioned the aramids which structures have a poly-para-oriented form or a form close thereto, such as poly(paraphenylene terephthalamide), poly(4,4'benzanilide terephthalamide), poly(paraphenylene-4,4'-biphenylenedicarboxylic acid amide) and poly (paraphenylene-2,6-naphthalenedicarboxylic acid amide or copoly(para- phenylene/3,4'-oxydiphenylene terephthalamide). The use of poly(paraphenylene terephthalamide), also indicated as PPTA may be preferred. Para-aramid fibers are commercially available under, int. al., the trade names Twaron ® and Technora ®, meta-aramid fibers are commercially available under, int. al., the trade name Teijinconex ®.

[0017] In another embodiment as synthetic fiber polyethylene is used. Polyethylene according to this invention includes homopolymers of ethylene and copolymers of ethylene with a co-monomer which is another alpha-olefin or a cyclic olefin both with generally between 3 and 20 carbon atoms. Examples include propene, 1-butene, 1-pentene, 1-hexene, 1-heptene, 1-octane, cyclohexene etc. The use of dienes with up to 20 carbon atoms is also possible, e.g. butadiene, 1-4 hexadiene or dicyclopentadiene. The amount of (non-ethylene) alpha-olefin in the ethylene homopolymer or copolymer used in the process according to the invention preferably is at most 10 mole%, preferably at most 5 mole%, more preferably at most 1 mole%. If a (non-ethylene) alpha-olefin is used, it is generally present in an amount of at least 0.001 mol%, in particular at least 0.01 mole%, still more in particular at least 0.1 mole%. Obviously, this means that where ethylene is mentioned as a monomer that the monomer can also include at most 10 mole%, preferably at most 5 mole%, more preferably at most 1 mole% of a (non-ethylene) alpha-olefin monomer or cyclic olefin monomer based on the total amount of monomers.

Preferably, ultra high molecular weight polyethylene (UHMWPE) is used. UHMWPE means that the average molecular weight of the polyethylene is higher than 0.5 million g/mol. It is well-known how by solid-state processing tapes can be produced from polyethylene. For example, EP2385963 describes how a film and tapes can be produced from polyethylene. Such tapes can further processed to obtain fibers or fibrillated tapes, as e.g. described in EP2300644. The polyethylene tapes or fibers can be used in the tracking fiber and linear tension member according to the invention as synthetic polymer after having been provided with a composition.

[0018] Polyesters are polymers synthesized from dicarboxylic acid or its ester-forming derivative and a diol or its ester-forming derivative, including the so-called liquid crystal polyesters.

Examples of polyesters include, polyethylene terephthalate, polybutylene terephthalate, polycyclohexanedimethylene terephthalate, polytrimethylene terephthalate (a.k.a., polypropylene terephthalate), polyethylene naphthalate and polyethylene-1,2-bis(2chlorophenoxy)ethane-4,4'-dicarboxylate.

[0019] Liquid crystal polyester (LCP) is a polyester which exhibits mesomorphism in a molten state, and is melted at a temperature of 450°C or lower. The liquid crystal polyester is a liquid crystal polyester amide, a liquid crystal polyester ether, a liquid crystal polyester carbonate, or a liquid crystal polyester imide. The liquid crystal polyester is preferably a whole aromatic liquid crystal polyester in which only an aromatic compound is used as a raw monomer. Typical examples of the liquid crystal polyester include (I) a liquid crystal polyester obtained by polymerizing (polycondensing) an aromatic hydroxycarboxylic acid, with an aromatic dicarboxylic acid, and at least one kind of a compound selected from the group consisting of an aromatic diol, an aromatic hydroxyamine and an aromatic diamine; (II) a liquid crystal polyester obtained by polymerizing plural kinds of aromatic hydroxycarboxylic acids; (III) a liquid crystal polyester obtained by polymerizing an aromatic dicarboxylic acid with at least one kind of a compound selected from the group consisting of an aromatic diol, an aromatic hydroxyamine and an aromatic diamine; and (IV) a liquid crystal polyester obtained by polymerizing a polyester such as polyethylene terephthalate with an aromatic hydroxycarboxylic acid. Herein, a part or all of an aromatic hydroxycarboxylic acid, an aromatic dicarboxylic acid, an aromatic diol, an aromatic hydroxyamine and an aromatic diamine may be changed, respectively independently, to a polymerizable derivative thereof.

[0020] For purposes of this application, the term polybenzazole includes polybenzoxazole (PBO) homopolymers, polybenzothiazole (PBT) homopolymers and random, sequential and block copolymers of PBO and/or PBT.

[0021] Polyamide as used in this application refers to any of the various generally linear, aliphatic polycarbonamide homopolymers and copolymers which are typically meltspinnable and, when drawn, yield fibers having properties suitable for industrial applications. For example, poly(hexamethylene adipamide) (6,6 nylon) and poly(t-caproamide) (6 nylon), poly(tetramethylene adipamide) (4,6 nylon) are typically-used polyamides for industrial fibers. The invention is also applicable to copolymers and mixtures of polyamides.

[0022] For the purpose of this invention polypropylene includes isotactic, syndiotactic and atactic polypropylene and polypropylene copolymers.

Polypropylene copolymers for the purpose of this invention include polypropylenealpha-olefin copolymers and poly(propylene-styrene) copolymers. Examples for suitable alpha-olefins include but are not limited to polyethylene (PE), polybutylene, and poly(4methyl-1-pentene). The polypropylene copolymers include polypropylene block copolymers and polypropylene random copolymers.

The polypropylene copolymers comprise at least 60% propylene units. A preferred polypropylene copolymer is a propylene-ethylene copolymer, where e.g. the amount of ethylene monomers varies between 1 and 10 mole% based on the total amounts of monomers which are used to produce the polymer, preferably between 2 and 5 mole%.

[0023] For the purpose of this invention Polyacrylonitrile (PAN) is defined as a synthetic, semicrystalline organic polymer with the linear formula $(C_3H_3N)_n$, including copolymers made from mixtures of monomers with acrylonitrile as the main component. Fibers comprising PAN are the chemical precursor of high-quality carbon fiber. The definition also includes stabilized PAN fibers, that means fibers which have been converted from thermoplastic PAN to a non-plastic cyclic or a ladder compound (as described by Rahaman et al., Polymer Degradation and Stability 92 (2007), 1412-1432).

[0024] In one embodiment the composition of the tracking fiber comprises at least one wax, resin, oil, polymer compound or at least one melt, solution or dispersion (including emulsions) or any mixture of those. The polymer can e.g. be polyurethane, polyester, polyamide or a mixture thereof. The solution can be based on an organic solvent or it can be an aqueous solution.

In one embodiment the wax, resin, oil, polymer compound or melt, solution or dispersion or any mixture of those functions as a carrier material for the component of the composition.

The composition comprises at least one component chosen from:

i) an alkali metal, an earth alkali metal, a metal chosen from cerium, neodymium, zinc, iron, zirconium, tantalum, silver, gold, platinum, titanium or iridium, a metal alloy and/or a derivative thereof,
ii) a halogen and/or derivative thereof, or
iii) an organic compound.

[0025] If the component is a metallic one, it preferably comprises cerium, neodymium, rubidium, zinc, iron, zirconium, tantalum, barium, silver, gold, platinum, titanium or iridium.

The composition can also comprise derivatives of such an alkali metal, an earth alkali metal, a metal chosen from cerium, neodymium, zinc, iron, zirconium, tantalum, silver, gold, platinum, titanium or iridium, a metal alloy and/or a derivative thereof, and of halogens as e.g. salts, soaps, organo-metal or other complexes. Suitable are oxides, and salts as nitrides, carbides, sulphates, as e.g. pure zirconium dioxide, stabilized zirconium dioxide, zirconium nitride, zirconium carbide, tantalum pentoxide, barium sulphate, ferric oxides or zinc oxide.

Soaps are salts of fatty acids e.g. from triglycerides. Suitable soaps are zinc stearate, zinclaurate, zincoleate, bariumstearate, bariumoleate, aluminium stearate, aluminiumoleate, potassiumstearate and sodiumstearate.

Organo-metals are carbon-metal compounds containing at least one metal-carbon (M-C) bond where the carbon is part of an organic group. Suitable organo-metal components according to this invention are e.g. dimethylzinc, ferrocene, tetracarbonyl nickel, diethylmagnesium.

[0026] Metal complexes (or coordination complexes) consists of an metallic atom or ion surrounded by an array of bound molecules or anions. Suitable metal complexes according to this invention are e.g. pentacarbonyliron(0), ammoniumtetrachlorocuprate, hexaammineiron(III)nitrate.

[0027] Metal alloys are combinations of one metal and at least one other metal or non-metal. All suitable metals can be chosen to prepare a metal alloy. Suitable examples are e.g. iron alloys.

[0028] In another embodiment the component is chosen from a halogen or derivative thereof. In one embodiment components are chosen with a high gyromagnetic ratio. This is especially advantageous if NMR is used as non-destructive detection technique. Fluorine and fluorides are examples of such a component.

[0029] The derivative of the halogen can be a salt, soap or organo-halogen compound. Suitable examples are iodine or bromine derivates, as e.g. alkali iodides, iodated aromatics, iodated aliphatics, iodated oligomers, iodated polymers as well as mixtures of such substances. E.g. iodine, bromine, potassium iodide, potassium bromide, silver iodide, silver bromide, rubidium iodide or rubidium bromide can be used.

[0030] The component can also be chosen from an organic compound.

Suitable organic compounds are carbohydrates, amino acid, organic acids, or heterocyclic compounds.

Specific examples include glucose, mannitol and caffeine.

[0031] In one embodiment, the composition comprises a combination of any of the aforementioned components.

[0032] For terahertz analysis as non-destructive testing method it is advantageous if the component and/or the whole composition has a terahertz absorption range of 0.1-10 THz, preferably 0.1-2 THz, also depending on the synthetic polymer.

[0033] The tracking fiber comprises a synthetic polymer and the composition. In one embodiment, the tracking fiber consists of a synthetic polymer in the form of a synthetic fiber and the composition. In one embodiment, the composition is applied to the synthetic polymer fiber to obtain the tracking fiber. The composition can be applied in different forms, also depending on the application technique, e.g. solutions with organic solvent or as aqueous solution, dispersed as powder in oils, (curable) resins or hotmelts of polymers. In one embodiment a dispersion of the component in a medium such as wax or resin is made and combined with a wax or resin of a second emulsion. The emulsion and dispersion can subsequently be combined to result in a composition with different concentrations of the component which can subsequently be applied to the fiber to result in the tracking fiber.

[0034] To apply the component or a composition comprising said component, every method is suitable by means of which the desired amount of material solids can be applied to the fibers.

The composition can be applied to the fiber by a number of techniques not limited to glueing, coating, dipping, application as a finish, spraying or lamination, which is especially advantageous for tapes.

[0035] For example, the composition can be applied during the production process of the fibers, using a nozzle or with an applicator or with a kiss roll, after the washing and prior to the drying, after which the fibers are dried and wound up. The application with a kiss roll means that a rotating roll is partially immersed in a bath, in which the component is present, e.g. as an aqueous solution. A film forms on the part of the roll protruding from the bath. The fibers are brought into contact with the film and thereby finished or coated. Further, the composition application can also be implemented in a process downstream from the fiber production. For this purpose, the fibers can be e.g. unwound from the roll and brought into contact with the material or composition. It is also possible to implement the application in two or more steps that take place in series, wherein e.g. a first step occurs during the production process of the fibers and a second step occurs in a process downstream of the fiber production. However, the composition can be applied by every method which the person skilled in the art considers suitable, e.g. also chemical vapor deposition or fluid bed application techniques.

[0036] By this a tracking fiber is obtained which comprises 0.2-50 wt% of solids of the composition based on the weight of the synthetic polymer fiber. Preferably, that amount is 1 - 25wt%.

In one embodiment the tracking fiber of the current invention comprises 0.2-50 wt% of the component based on the weight of the synthetic fiber, preferably the tracking fiber comprises 0.2-20 wt%, more preferably 0.5-15 wt%, even more preferably 1-10 wt% of the component.

[0037] The amount of the composition or component depends on the chosen component, the detection technique and the amount of tracking fiber in the linear tension member. In any case, the amount of the component has to be chosen such that the tracking fiber with the chosen non-destructive testing method is distinguishable from the other fibers of the linear tension member.

[0038] The current invention is also directed to a linear tension member comprising a tracking fiber for non-destructive testing of the linear tension member, wherein the tracking fiber is characterized in that it comprises a fiber and a composition, wherein the fiber comprises a synthetic polymer and the composition comprises at least one component chosen from

i) an alkali metal, an earth alkali metal, a metal chosen from cerium, neodymium, zinc, iron, zirconium, tantalum, silver, gold, platinum, titanium or iridium, a metal alloy and/or a derivative thereof,
ii) a halogen and/or derivative thereof, or
iii) an organic compound, wherein the transition metal is chosen from.

[0039] Besides at least one tracking fiber the linear tension member may further comprise fibers of a synthetic polymer, either of the same synthetic polymer as the tracking fiber or made from a different synthetic polymer. The fibers of the

linear tension member which are not tracking fibers are indicated as load bearing fibers.
In one embodiment the tracking fibers are the same fibers as the load bearing fibers but provided with the composition. In this embodiment the tracking fiber and the load bearing fiber are expected to be most similar in their properties.

[0040] The tracking fiber comprised in the linear tension member is the same as described in claims 2-9 and the embodiments of the tracking fiber described above.

[0041] In one embodiment, the load bearing fibers are present in an amount of at least 60 wt.% of the linear tension member, and contribute to the linear tension member properties, and the tracking fiber is present in an amount of at most 40 wt.% of the linear tension member and contributes to the possibilities for the non-destructive testing (e.g. by X-ray, terahertz, permanent magnetic field, NMR or electromagnetic analysis).
It should be noted that the indication for the tracking fiber that it contributes to the possibilities of non-destructive testing does not mean that it cannot or should not contribute to the linear tension member properties also.
It may be preferred for the linear tension member to comprise the load bearing fibers in an amount of at least 70 wt.%, in particular at least 80 wt.% based on the weight of fibers of the load bearing member. As a maximum, an amount of 99.99 wt% may be mentioned in general. The tracking fiber may in some embodiments be present in an amount of at most 30 wt%, in particular at most 20 wt.%. As a minimum value, an amount of at least 0.01 wt% may be mentioned in general.
Determination of the amount of tracking fiber suitable for a particular situation depends upon a number of parameters. A first parameter is the amount of fiber required to ensure that the distribution of the tracking fiber throughout the linear tension member is such that changes of the property of the tracking fiber can be observed by non-destructive testing methods. A larger number of strands may require a larger amount of tracking fiber, to ensure that the tracking fiber can be incorporated in a sufficient number of strands to obtain a sufficient signal during non-destructive testing.

[0042] Accordingly, the amount of tracking fiber in the linear tension member is dependent on the linear tension member diameter, the type of component ,and the amount of the component in the tracking fiber and the non-destructive testing method. The visibility of the tracking fiber can also be adjusted by using one tracking fiber per linear tension member, multiple tracking fibers in a strand of the linear tension member, a full strand of tracking fibers or even tracking fibers inserted in several strands of the linear tension member.
The tracking fiber may be incorporated into the linear tension member in various manners. In one embodiment it is included in a strand together with load bearing fibers. In another embodiment it is used as a separate strand. The linear tension member can include one or more of such strands.
The term strand is used for one or more cords which, together with other strands, are combined to form a structured linear tension member.

[0043] In one embodiment the linear tension member comprises multiple fibers. The linear tension member comprises load bearing fibers and at least one tracking fiber which can be combined by braiding, twisting, beading, unidirectionally laying (in parallel bundles), winding, intermingling or any combination thereof. For example, twisted and parallel laid bundles of fibers can be combined in one linear tension member.
It is also possible to take a number of cords obtained from combining strands and combine them to a larger linear tension member. Tracking fibers can also be included in the jacket of the linear tension member or in jackets applied to individual strands. Strands can e.g. be combined by braiding, twisting, beading, stranding or they can be laid in parallel.
In one embodiment for at least some of the fibers, strands or cords the distance of said elongate elements to a central longitudinal axis within the linear tension members varies over the length of the linear tension member. This means that at least some of the elongate elements are arranged to show a repeating oscillation pattern. Generally, the yarn in such a linear tension member has a helix angle of more than 2°.
In another embodiment the elongate elements of the linear tension member are combined by laying at least two yarns or strands in parallel and surrounding them by a sleeve, wrap or polymeric coating to keep the individual yarns or strands together and to protect the linear tension member. Generally, if arranged in parallel, the yarns or strands have a helix angle of 2°or less. Such an arrangement results in a unidirectional (UD) linear tension member.

[0044] A mantle can protect the linear tension member from particle ingress, e.g. from dirt particles. The mantle, possibly in form of a sleeve, wrap or coating can cover the whole length of the linear tension member, only parts of it or e.g. only the splice site.
It is also possible that strands which comprise parallel laid yarns and strand which comprise yarns with a helix angle of more than 2° are combined to one linear tension member.

[0045] The present invention pertains also to the use of a tracking fiber according to any one of claims 1-9 in a method for non-destructive testing of the condition of synthetic linear tension members. The method can be chosen by the person skilled in the art from a wide range of available non-destructive testing methods depending on the applied component and composition, the desired precision of the method, the conditions of use of the linear tension member and so on. In one embodiment the linear tension member in use is subjected to X-ray, terahertz, permanent magnetic field, electromagnetic analysis or NMR as non-destructive testing method. However, also possible is e.g. aircoupled ultrasound as testing method.

The method comprises the following steps: a pattern derived from the tracking fiber is analyzed by a non-destructive testing method, this pattern is compared to a standard pattern and the comparison is used to determine the condition of the linear tension member and if it is fit for use.

Preferably, the standard pattern is obtained from a new linear tension member also comprising the tracking fiber.

[0046] In one embodiment, the standard pattern and the pattern of the linear tension member in use are derived from a repeating oscillation pattern associated with the structure of the linear tension member, and the comparison between the two patterns is a measure for the change in the repeating oscillation pattern associated with the structure of the linear tension member caused by use.

After manufacture, the oscillating patterns in the linear tension member are regular over the linear tension member length. During use, the oscillating patterns in the linear tension member may change. They may, e.g., be either lengthened by stretching of the linear tension member, or they may become irregular due to irregular deformation of the linear tension member during use. Therefore, the difference between the standard pattern derived from the repeating oscillation pattern associated with the structure of the linear tension member and the pattern derived from the linear tension member in use can serve as an indication for the changes in the linear tension member, and therewith for the deterioration of the linear tension member during use.

[0047] In another embodiment the pattern is not directly derived from the configuration of the tracking fiber in the linear tension member but it is derived from the signal output of the detection method (e.g. from image processing or spike analysis). This output can e.g. be a signal pattern, a spectrum or an image derived from the measured signal, or a change in signal amplitude/frequency. This signal pattern can be compared with the signal pattern of a new linear tension member. For example, a breakage of the tracking fiber would interrupt the measured signal and therefore present another pattern than a new, not broken linear tension member. The advantage of this embodiment is that the method of this invention can also be used for linear tension members comprising parallel strands, e.g. so-called UD linear tension members (unidirectional ropes).

[0048] The non-destructive testing method can be chosen from X-ray, terahertz, permanent magnetic field, electromagnetic analysis or NMR. These methods are used to obtain a pattern of the tracking fiber in the used and in the reference linear tension member.

[0049] In one embodiment the patterns are derived from X-ray transmission data. The use of X-ray transmission is advantageous, int. al., because it is well known for use in other applications, and therewith accessible technology. Analysis of data generated through X-ray transmission relies on the detection of density differences. Therewith, the suitability of a linear tension member for use in the method of the invention may be improved by increasing the density difference between the tracking fiber and the load bearing fiber in the linear tension member.

[0050] In another embodiment the patterns are derived from terahertz analysis.

Terahertz analysis uses terahertz electromagnetic radiation for non-destructive testing. With frequencies between 0.1 and 10 terahertz (THz), the spectral range of terahertz lies between microwaves and infrared radiation. The corresponding wavelengths range from 3 mm to 30 μm.

[0051] Terahertz waves unite the advantages of the two neighboring spectral regions: high penetration depth and low scattering combined with good spatial resolution are characteristic properties of terahertz waves. Unlike UV radiation or X-rays, for example, terahertz waves do not change the chemical structure. Consequently, they are not harmful to humans and present no health risks.

Terahertz analysis is based on the different amounts of absorption, scattering and reflection of terahertz radiation by different materials. Terahertz analysis can additionally be based on frequency specific, spectroscopic behavior of different materials.

[0052] In another embodiment, a permanent magnetic field is used to determine a pattern of the tracking fiber in the linear tension member. The permanent magnetic field is generated by the tracking fiber which is comprised in the linear tension member. An array of magnetic field detectors in close proximity to the linear tension member can be used to derive the pattern. An example of such an array is a circular arrangement of detectors around the linear tension member. Another example of such an array is a row of detectors along the length of the linear tension member. Any combination of these arrangements is also possible.

[0053] In another embodiment electromagnetic analysis is used to determine the pattern. The electromagnetic analysis uses an electromagnetic field with a frequency in the range 10 kHz to 5 GHz for non-destructive testing. The electromagnetic field is generated by a transmitter coil in close proximity to the linear tension member, in some cases the linear tension member can travel through the center of the coil. The electromagnetic field can also be generated between two plates of a capacitor between which the linear tension member travels. Several configurations can be envisioned to extract status information from the linear tension member using electromagnetic analysis.

The following embodiments are non-limiting examples of electromagnetic analysis.

In one embodiment, the coil which transmits the electromagnetic field can be one of the components which determine the frequency of the electromagnetic field which is generated by the coil. In this case, the frequency of the electromagnetic field is influenced by the constitution of the linear tension member.

[0054] In a second embodiment, a magnetic flux concentrator arrangement can be used. The transmitter coil is electrically driven by a high frequency carrier which is modulated in amplitude by a low frequency signal. The coil is placed perpendicular to the linear tension member with a sensor between the linear tension member and the coil which is sensitive to the electromagnetic field, e.g. a Hall sensor or a second, receiver coil. Depending on the proximity of linear tension member components which influence the electromagnetic field to the sensor, the field will become stronger or weaker. The signal from the receiver coil can be converted using synchronous detection by which only the low frequency signal remains. In this case, the amplitude of the low frequency signal contains the information about the constitution of the linear tension member.

[0055] In another embodiment, the linear tension member travels through the transmitter and receiving coils. The receiving coils are located on both sides of the transmitter coil. Signals from both receiving coils can be used separately and as a difference signal to obtain the information about the constitution of the linear tension member.

[0056] In another embodiment, the linear tension member travels between two plates of a capacitor. In case the capacitor is one of the frequency determining components, the proximity of linear tension member components which influence the electromagnetic field will have effect on the generated frequency. The frequency of the electromagnetic field will contain information about the constitution of the linear tension member.

[0057] The electromagnetic and permanent magnetic analyses used in the invention are different from the magnetic flux leakage method widely used for testing of steel wire linear tension members.

[0058] NMR (Nuclear magnetic resonance) can also be used as a non-destructive detection method. NMR determines which nuclei in a magnetic field absorb and re-emit electromagnetic radiation. This energy is at a specific resonance frequency which depends on the strength of the magnetic field and the magnetic properties of the isotope of the atoms; often between 60 and 1000 MHz. NMR allows the observation of specific quantum mechanical magnetic properties of the atomic nucleus.

A key feature of NMR is that the resonance frequency of a particular substance is directly proportional to the strength of the applied magnetic field. It is this feature that is exploited in imaging techniques; if a sample is placed in a non-uniform magnetic field then the resonance frequencies of the sample's nuclei depend on where in the field they are located. NMR is a widely used technique, e.g. also in medical applications.

[0059] Depending on the nature of the linear tension member, it may be desirable to adapt the composition of the linear tension member to make it particularly suitable for one of the methods used in the present invention.

[0060] Analysis of data generated through X-ray, terahertz, permanent magnetic field or electromagnetic analysis relies on the detection of differences between the tracking fiber and the load bearing fibers. For X-ray, this is a difference in density, while for terahertz it is the different absorption, scattering or reflection spectrum, for permanent magnetic analysis it is the permanent magnetic permeability and for electromagnetic analysis they are the magnetic permeability and dielectric properties, depending on the specific detection technique chosen. Therewith, the suitability of a linear tension member for use in the method of the invention may be improved by increasing the difference between the tracking fiber and the load bearing fiber with regard to the measured characteristic in the linear tension member.

[0061] In one embodiment more than one component is applied to the fiber to obtain a tracking fiber. This means that the tracking fiber comprises the fiber and more than one component. The advantage of this embodiment is that the same tracking fiber can be used in different analysis techniques. In another embodiment a linear tension member comprises more than one sort of tracking fiber, each of the sorts of tracking fiber provided with a different component. Also in this embodiment the same linear tension member can be subjected to different analysis techniques.

In another embodiment the component is chosen such that it can be detected with different analysis techniques. For example, if the tracking fiber comprises a metallic component or derivate, this component can be detected with X-ray analysis because of the difference in density but also with terahertz analysis, because of the difference in absorption, scattering or reflection between the synthetic fiber and the component. If such a component is ferromagnetic or paramagnetic it can also be detected via electromagnetic analysis as described above or by using a permanent magnetic field.

[0062] Magnetism is a class of physical phenomena that includes forces exerted by magnets on other magnets. It has its origin in electric currents and the fundamental magnetic moments of elementary particles. These give rise to a magnetic field that acts on other currents and moments. All materials are influenced to some extent by a magnetic field. The strongest effect is on permanent magnets, which have persistent magnetic moments caused by ferromagnetism. Most materials do not have permanent moments. Some are attracted to a magnetic field (paramagnetism); others are repulsed by a magnetic field (diamagnetism); others have a much more complex relationship with an applied magnetic field (spin glass behavior, antiferromagnetism, antiferrimagnetism).

[0063] The embodiment where tracking fibers comprising different components are present in one linear tension member or a pattern derived from one component can be obtained with different techniques is especially advantageous. In such a case a linear tension member comprising the tracking fiber can be subjected to different analysis methods described in this invention. For example, electromagnetic analysis can be used for quick testing while X-ray analysis can be used for a more detailed inspection of the linear tension member. It is advantageous to use a method which can be used at higher testing speeds continuously and online. This inspection can take place during use of the linear tension member. A slower inspection method can then be used for in-depth, detailed analysis.

[0064] The following examples and figures describe the invention in more detail but do not limit the scope of the invention.

Fig. 1 shows optical (upper panel) and XRF images (lower panel) of a twisted bundle of aramid fibers comprising a fiber coated with a ZnO-comprising composition.

Fig. 2 shows an X-ray differential phase contrast image (absorption) of a rope comprising bundles of aramid fibers and a bundle of aramid fibers coated with a composition comprising ZnO.

Fig. 3 shows optical (panels 1 and 3) and XRF images (panels 2 and 4) of UHMWPE tape bundles comprising a UHMWPE tape coated with a ZnO-comprising composition.

Panels 1 and 2 show tapes which were fibrillated, while panels 2 and 4 show 2mm wide tapes.

<u>Example 1 - Aramid tracking fibers</u>

[0065] Tracking fibers with a coating of a component were prepared for X-ray inspection. The tracking fiber in this case is an aramid fiber coated with a metal component. A coating composition was prepared from a emulsion comprising wax and a dispersion of ZnO. The emulsion was an emulsion available from BYK CERA containing 35 % of wax (commercially available as Aquacer 1547). The dispersion was a dispersion available from Evonik containing 34% of ZnO (commercially available as PI VP Disp ZnO 20 DW). The emulsion and the dispersion were mixed together to have different concentrations (8, 16 and 24wt% based on the weight of the composition) of the ZnO in the composition. The composition was brought to a total solid content of 32 wt%.
The above described composition was applied to Twaron 1000 (1680 dtex/f1000) fibers using a liquid applicator. The composition was applied onto the fibers in an amount of 12 wt% (based on the weight of the fiber), corresponding to a ZnO concentration (i.e. the component) of 3, 6 and 9 wt% based on the weight of the fiber respectively. Immediately after application of the composition, the fiber was dried in an oven at 160 °C for a time of about 10 sec.

[0066] This tracking fiber was then tested for its visibility in an X-ray technique. Towards this end, one of the tracking fibers was bundled together with 20 untreated aramid fibers (i.e. load bearing fibers) of the same type. This bundle was twisted to obtain a periodic structure within the bundle giving an oscillatory pattern in the linear tension member construction. The fiber bundle was loaded onto a sample holder in a X-ray fluorescence machine (XRF). XRF is widely used for elemental analysis and chemical analysis particularly in the detection of metals. A scanning of the fiber bundle over a particular area gives images of the bundle and the position of the tracking fiber. Such an image using a tracking fiber containing ZnO is shown in Fig. 1 in the lower panel (shown is the sample with 9 wt% ZnO on fiber). In the upper panel an optical image of the same fiber bundle is shown.

<u>Example 2 - Aramid rope comprising tracking fiber</u>

[0067] The ZnO-comprising tracking fiber from example 1 was used to produce an aramid rope of 10mm diameter. The rope consists of 12 twisted strands and each strand contains 32 fibers. One strand of 32 fibers consists only of tracking fibers. The rope sample was then scanned using an X-ray differential phase contrast imaging (XPCI) technique. The parameters used for the measurement are: X-ray tube voltage = 40kV; X-ray tube current = 22.5 mA; Pixel size: 45 micrometers; exposure time: 1.5 min per image; distance between source and detector = ~1.4 m. An image of the rope samples containing ZnO tracking fiber from XPCI in absorption mode is given in Fig. 2 (shown is the sample with 9 wt% ZnO on yarn).

[0068] As is clear from the images, the pattern of the tracking fiber is well visible. This also means that information on deviations in the spatial phase between the strands can also be obtained from these images. These informations can be used to assess the condition (e.g. breaks, elongation) of the linear tension member.

[0069] The tracking fiber and the non-coated fiber were tested for their mechanical properties according to ASTM-D7269 - 07 ("Standard Test Methods for tensile testing of aramid yarns"). Both samples were tested on a standard tensile tester under the following conditions: scan frequency - 50 Hz, pre-tension 20 mN/tex, clamp speed - 250 mm/min, gauge length - 500 mm.
The results are shown in table 1. The results show that the properties of the load bearing fiber, in this case Twaron 1000 and the tracking fiber, in this case Twaron 1000 with ZnO differ only little. Therefore, the mechanical properties are similar and the tracking fiber is expected to be a good indicator for the condition of the linear tension member.

Table 1: Comparison of the mechanical properties of the load bearing fibers (uncoated, Twaron1000) and the tracking fiber (coated with a high density material, ZnO tracking fiber)

Mechanical characteristic	Twaron1000	ZnO-coated tracking fiber, based on Twaron1000
Breaking force [N]	375	381
Breaking tenacity [mN/tex]	2187	1988
Modulus [GPa]	53	45
Elongation at break [%]	3.5	3.7
Toughness at rupture [J/g]	36	34

<u>Example 3 - UHMWPE bundle comprising a tracking fiber</u>

[0070] In a similar way as described in examples 1 and 2 compositions containing a component were applied to UHMWPE samples. For this purpose, UHMWPE (ultra-high molecular weight polyethylene) tapes (Endumax®, from Teijin Aramid) were used. Experiments were carried out with regular 2 mm wide tapes and also on fibrillated polyethylene (PE) tapes.

A composition was prepared from a first emulsion comprising a medium of styrene isoprene block copolymer and a second dispersion of ZnO. The first emulsion was an emulsion available from Trüb Emulsions containing 36 wt% of solids (commercially available as Tecpol KW 2401/20). The second dispersion was a dispersion available from Evonik containing 34 wt% of ZnO (commercially available as PI VP Disp 20DW). The first emulsion and the second dispersion were mixed together to have different concentrations (8, 16 and 24 wt% based on the weight of the composition) of ZnO in the composition. The composition was brought to a total solid content of 32 wt %.

[0071] In a similar way as for the fibers, the composition was applied to the UHMWPE tapes and fibrillated tapes. For the XRF measurements, as mentioned in the case of aramid fibers, one tracking tape was bundled together with 20 uncoated PE tapes. This was done for tapes and fibrillated tapes separately. The bundle was then given a twist in order to obtain an oscillatory pattern of the tracking fiber within the bundle. The bundles were tested using XRF imaging. Fig. 3 shows images of the UHMWPE bundles containing one tracking fiber/tape (shown is the sample with 24wt% ZnO coating composition). In the first and third panel an optical image of the bundles is shown and in the second and fourth panel an XRF image of the bundles is shown. Panels one and two show the results for fibrillated tapes (multiple images compiled) and panels three and four show results for tapes (multiple images compiled). The images show that the tracking fiber can be distinguished from the non-coated fibers and gives a well-visible image in the XRF imaging. A break or other disturbance of the tracking fiber could be identified in this way. This information can then be used to determine the condition of the linear tension member.

<u>Example 4 - Permanent magnetic tracking fiber</u>

[0072] An aramid tracking fiber comprising a permanent magnetizable coating was prepared using the following procedure. 80g of MQP S-11-9 powder (obtained from Magnaquench, comprising a Nd-Pr-Fe-Co-Ti-Zr-B alloy) was mixed with a 5:50 mixture of Impranil DLS (an aliphatic polyester-polyurethane dispersion, obtained from Bayer®) and Genapol PTU (a filament lubricant, obtained from Clariant). Twaron 1000® yarn (1680f1000) without any finish was dipped into the described coating and the excess was removed by using an extrusion die of 1.2 mm diameter. The yarn was then dried at 180°C in a tube oven at a yarn speed of 2.8min/min. The coated yarn was subsequently permanently magnetized.

Claims

1. A tracking fiber for non-destructive testing of linear tension members **characterized in that** the tracking fiber comprises a fiber and a composition, wherein the fiber comprises a synthetic polymer and the composition comprises at least one component chosen from:

i) an alkali metal, an earth alkali metal, a metal chosen from cerium, neodymium, zinc, iron, zirconium, tantalum, silver, gold, platinum, titanium, molybdenum or iridium, a metal alloy and/or a derivative thereof,
ii) a halogen and/or derivative thereof, or

iii) an organic compound.

2. A tracking fiber according to claim 1 wherein the synthetic polymer is chosen from aramid, polyethylene, polyester, polyamide, polypropylene, polybenzazole and polyacrylonitril.

3. A tracking fiber according to claim 1 or 2 wherein the composition comprises a wax, resin, oil, polymer, or solutions, emulsions or dispersions of a wax, resin, oil or polymer.

4. A tracking fiber according to any one of claims 1 to 3 wherein the derivative is a salt, soap or an organo-metal or organo-halogen complex.

5. A tracking fiber according to any one of the claims 1 to 4, wherein the halogen or its derivative is iodine, bromine, potassium iodide, potassium bromide, silver iodide, silver bromide, rubidium iodide or rubidium bromide.

6. A tracking fiber according to any one of claims 1 to 5 wherein the component and/or the composition has a terahertz absorption in the range of 0.1 - 10 THz.

7. A tracking fiber according to any one of claims 1 to 6 wherein the organic compound is a carbohydrate, amino acid or organic acid.

8. A tracking fiber according to any one of claims 1 to 7 wherein the tracking fiber comprises 0.2-50 wt% of solids of the composition based on the weight of the synthetic fiber.

9. A tracking fiber according to any one of claims 1 to 8 wherein the tracking fiber comprises 0.2-50 wt% of the compound based on the weight of the synthetic fiber.

10. A linear tension member comprising a tracking fiber for non-destructive testing of the linear tension member, wherein the tracking fiber is **characterized in that** it comprises a fiber and a composition, wherein the fiber comprises a synthetic polymer and the composition comprises at least one component chosen from

i) an alkali metal, an earth alkali metal, a metal chosen from cerium, neodymium, zinc, iron, zirconium, tantalum, silver, gold, platinum, titanium or iridium, a metal alloy and/or a derivative thereof,
ii) a halogen and/or derivative thereof, or
iii) an organic compound

11. A linear tension member according to claim 10 which comprises multiple fibers of a synthetic polymer and at least one tracking fiber.

12. A linear tension member according to claim 10 or 11 wherein the fibers are combined by braiding, winding, unidirectionally laying, twisting or intermingling.

14. Use of a tracking fiber according to any one of claims 1-9 for non-destructive testing of the condition of a linear tension member.

15. The use according to claim 14 wherein the non-destructive testing method is chosen from X-ray, terahertz, electromagnetic, permanent magnetic field analysis or NMR.

Fig. 1

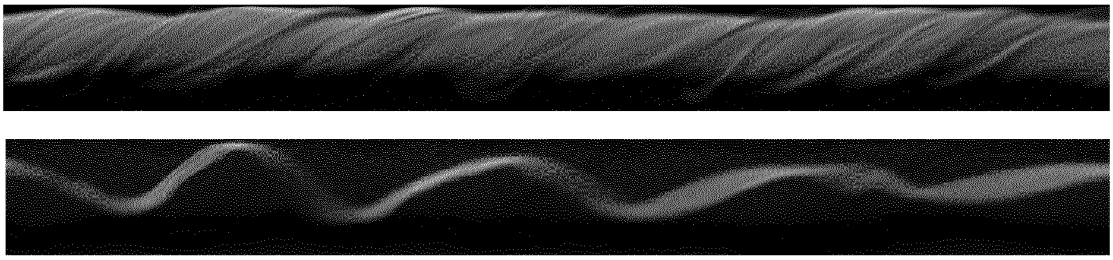


Fig. 2

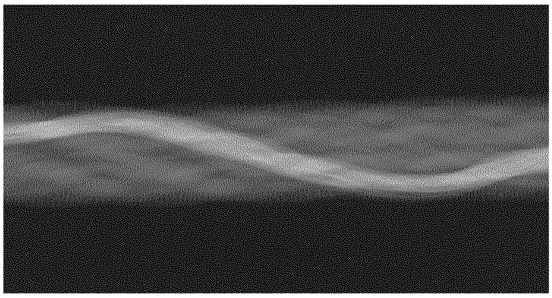
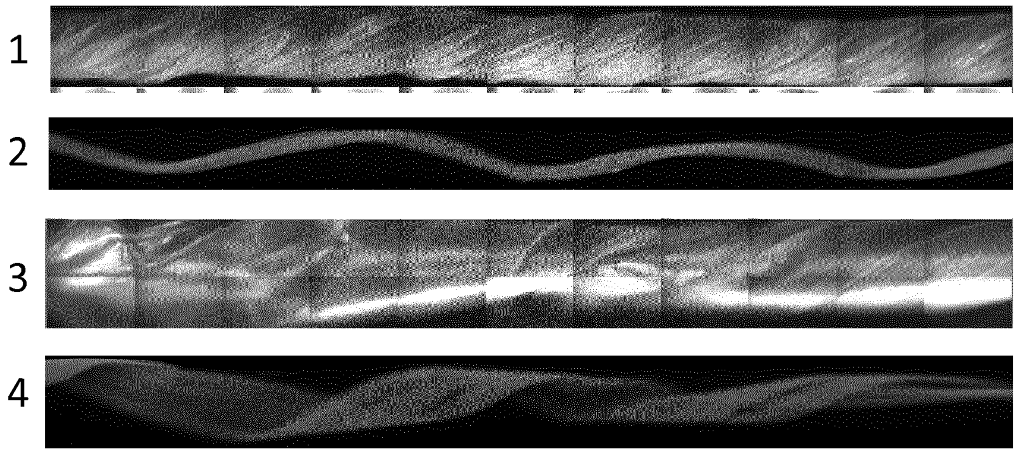


Fig. 3



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EUROPEAN SEARCH REPORT

Application Number
EP 13 18 2796

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X	DE 20 2010 013519 U1 (BARTHELS FELDHOFF GMBH & CO KG [DE]; GLEISTEIN & SOHN GMBH GEO [DE]; S) 25 November 2010 (2010-11-25) * the whole document *	1,2, 10-12,14	
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Y	WO 2009/137709 A1 (RHODE ISLAND BOARD OF GOVERNOR [US]; LUCHT BRETT L [US]; EULER WILLIAM) 12 November 2009 (2009-11-12) * abstract * * paragraph [0049] - paragraph [0050] *	1,2, 10-12,14	
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~~The present search report has been drawn up for all claims~~

1

Place of search	Date of completion of the search	Examiner
Munich	10 January 2014	Uhlig, Robert

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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Application Number
EP 13 18 2796

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

- [ ] Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

- [ ] No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

- [ ] All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

- [ ] As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

- [ ] Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

- [X] None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

  2, 10-12, 14(completely); 1(partially)

- [ ] The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number

EP 13 18 2796

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 2, 10-12, 14(completely); 1(partially)

    A fiber filled and/or coated with a composition

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2. claims: 3-5, 7-9(completely); 1(partially)

    Alternative compositions for claim 1

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3. claims: 6, 15

    Terahertz absorption property of the coated or filled fiber of claim 1

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 13 18 2796

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