DTU Library

A strain gauge

Mikkelsen, Lars Pilgaard; Gili, Jacopo

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
19 January 2017 (19.01.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/009365 A1

(51) International Patent Classification:
G01B 7/16 (2006.01) *G01L 1/22* (2006.01)

(21) International Application Number:
PCT/EP2016/066604

(22) International Filing Date:
13 July 2016 (13.07.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15176608.6 14 July 2015 (14.07.2015) EP

(71) Applicant: **DANMARKS TEKNISKE UNIVERSITET** [DK/DK]; Anker Engelunds Vej 101 A, 2800 Kgs. Lyngby (DK).

(72) Inventors: **MIKKELSEN, Lars Pilgaard**; Gyvelvej 6C, st.tv., 4000 Roskilde (DK). **GILI, Jacopo**; Carl Herslowsgatan 9, 211 47 Malmö (SE).

(74) Agent: **INSPICOS P/S**; Kogle Allé 2, 2970 Hørsholm (DK).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, 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, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, 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, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *of inventorship (Rule 4.17(iv))*

Published:
— *with international search report (Art. 21(3))*

(54) Title: A STRAIN GAUGE

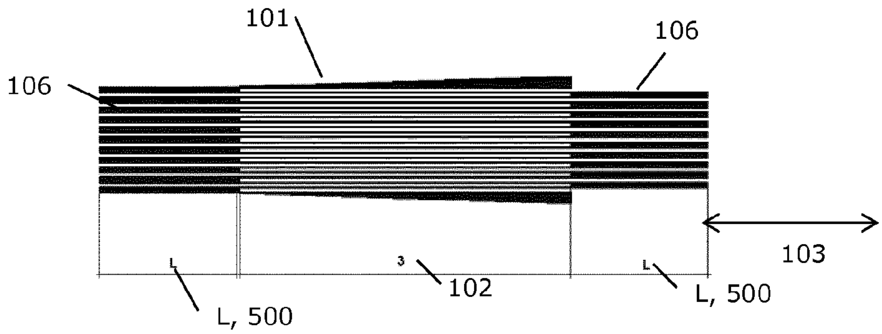

Fig. 5

(57) Abstract: The invention relates to a strain gauge of a carrier layer and a meandering measurement grid (101) positioned on the carrier layer, wherein the measurement grid comprises a number of measurement grid sections placed side by side with gaps in between, and a number of end loops (106) interconnecting the measurement grid sections at their ends. The end loops at both ends of the measurement grid extend a length (L, 500) in the axial direction in millimetres of a factor times a ratio between a width of a grid section and the gap distance, wherein the factor is larger or equal to 1.5. The invention further relates to a method for manufacturing a strain gauge as mentioned above.

WO 2017/009365 A1

A STRAIN GAUGE

Field of the invention

The present invention relates to a strain gauge comprising a carrier layer and a meandering measurement grid positioned on the carrier layer. The invention also relates to a method of manufacturing such strain gauge.

Background

Strain gauges are the most widely used strain and deformation measurement devices for metallic materials but are also used extensively for more compliant material such as polymers and polymer matrix composites, and are applied on materials with a stiffness ranging from just some Giga-Pascal (e.g. polyester or epoxy with an elasticity module of approximately E = 3 GPa) to hundreds of Giga-Pascal (e.g. Steel, E =200GPa or UD Carbon fiber composites of E=100-400 GPA).

The application of strain gauges ranges from material characterization of test coupons with geometrical dimensions in several millimetres and centimetres up to deformation measurements on structural components with dimensions of many meters.

A strain gauge in general consists of a metallic grid, which changes its electrical resistance during deformation. In a typical configuration, the out-of-plane thickness of the grid is in the order of approximately 5μm and is most often made of an approximative 180GPa stiff constantan alloy. In applications, the strain gauges are bonded to the test sample surface and the deformation of the test sample is then determined by measuring the changes of the electrical resistance in the strain gauge together with a calibration factor provided by the strain gauge manufacturer.

Uni-axial strain gauge models are commonly used in tests or on equipment for the determination or control of the stiffness of the test specimen or, in general, for the determination of uni-axial strain. Bi-axial 00°/90° gauges are typically utilized for determination of the Poisson's ratio of the material, or, in general for measurements of bi-axial strains at a 90° angle difference. Likewise, bi-axial 45°/-45° gauges are often applied for the determination of Shear Modulus and strain gauge rosettes are used to determine the full in-plane strain state.

Experience, and literature, however, report evidence of errors or large inaccuracies in measurements performed especially on highly and moderately compliant materials i.e. of lower stiffness. Some experimental studies have reported different determined elastic modulus values for identical polymer matrix based composites when comparing strains measurements from strain gauge with measurements from clip-on extensometers or based on optical methods. Such deviations are suspected to be caused by the stiffness mismatch between the strain gauge including a thin metal grid, and the test sample especially when more compliant, as described in detail in e.g. S. Zike and L.P. Mikkelsen. "Correction of Gauge Factor for Strain Gauges Used in Polymer Composite Testing". In: Experimental Mechanics (2013).

Experimental observations are supported by numerical simulation showing that strains inside a test material are altered significantly when bonding a strain gauge onto the test material surface. The strains locally in the test sample are reduced due to local stiffening where the deformation is constrained just below the strain gauge. Thereby, lower strains are transferred to the strain measuring grid. For sufficiently thick test coupons, the main contribution lowering the measured strain values is believed to arise from edge effects making the testing material deforming more in front of the metal grid and less under the grid. These edge effects are furthermore seen to become more pronounced for shorter strain gauges. This effect is sometimes referred to as the reinforcement effect.

Experimental measurements as well as numerical simulations show that for a strain gauge calibrated for a 200 GPa stiff material, the error on the measured E-modulus is 2-5% for a 10 GPa stiff biax-composite material and 5-15% for a 3 GPa stiff polymer material depending on the strain gauge length, and thus quite significant.

This in-accuracy or error of strain gauge measurements due to the stiffness mismatch between the strain gauge material and the test material may to some extent be reduced by additional calibrations of a conventional strain gauge on a material with the relevant stiffness. Nevertheless, for anisotropic composite material this is not practically possible as the material stiffness is highly dependent on the orientation of the strain gauge on the test sample. As an example a unidirectional glass fiber composite has an axial stiffness of 35-45GPa whereas the stiffness in 45 degree is less than 10GPa. Nevertheless, strain gauges are often used to determine the full stress strain curve of a given material where the strain gauge is calibrated on one single given material with a given fixed stiffness

Also, the use of correction parameters or gauge factors to reduce the in-accuracy or error of the strain gauge measurements on anisotropic and/or nonlinear materials is not effective or practically possible. Because the grid material of the strain gauge shows non-linear effects, a correction parameter or gauge factor should likewise be non-linear to obtain a more accurate stress-strain curve determination. This is however rarely taken into consideration in experimental measurements as the non-linearity of conventional strain gauges is also highly dependent on any non-linearity of the material which is tested and measured. As more compliant materials in general often show significant non-linearity (such as for example polymers), this problem of non-linearity leading to imprecise correction parameters or gauge factors is especially prone for strain gauge measurements on generally nonlinear materials and many anisotropic materials such as reinforced composites.

Conventional strain gauges have further proven to have difficulties in measuring strains of components comprising an outer superficial layer such as for example a coating layer or another protective layer. Here, the material mismatch between the outer layer and the main material of the component influences the strain measurements significantly as soon as the thickness of the outer layer exceeds in the order of 0.5 mm depending on the material types. This type of error measurement cannot be countered by calibration factors.

Nevertheless, strain gauges are used to a great extent as strain identification sensors in composite structures. In addition, the standards often recommend the use of a strain gauge as the most accurate strain measurement device during mechanical testing of polymer matrix composite materials.

Description of the invention

It is therefore an object of embodiments of the present invention to overcome or at least reduce some or all of the above described disadvantages of the known types of strain gauges by providing a strain gauge with improved performance especially when applied on anisotropic materials such as composites.

It is an object of embodiments of the invention to provide a strain gauge which yield more accurate strain or deformation measurements and with no or a reduced dependency of the stiffness or non-linearity of the tested material.

It is a further object of embodiments of the invention to provide a strain gauge which yield more constantly accurate strain or deformation measurements for different types of materials with elasticity moduli ranging from a few to hundreds of GPa such as for example in the range of 2-400 GPa.

It is a further object of embodiments of the invention to provide a strain gauge with reduced edge or reinforcement effects.

It is a further object of embodiments of the invention to provide a strain gauge which may be manufactured with few or minimal changes to conventional strain gauge manufacturing.

It is a further object of embodiments of the invention to provide a method of manufacturing a more precise or accurate strain gauge.

In accordance with the invention this is obtained by a strain gauge comprising a carrier layer and a meandering measurement grid positioned on the carrier layer, wherein the measurement grid is arranged such as to measure a deformation in an axial direction of the strain gauge. The measurement grid comprises:

- a number of measurement grid sections extending essentially in the axial direction and being placed side by side with gaps in between, and
- a number of end loops interconnecting the measurement grid sections at their ends.

Further, at least a plurality of the end loops at both ends of the measurement grid extend a length in the axial direction in millimetres of a factor times a ratio between a width of a grid section and the gap distance, wherein the factor is larger or equal to 1.5.

For a strain gauge of equally spaced grid sections of a fixed width, the total width of the measurement grid of the strain gauge then equals the number of grid sections times the grid section width (or wire width) plus the number of gaps (number of grid sections or wires minus one) times the gap distance.

However, it has been found that the ratio between the width of a grid section and the gap distance is an important dimensioning parameter in determining the length of the end loops

In general when using a strain gauge, the strain field of the specimen to be measured on is perturbed by the installation of the strain gauge. This effect is most evident when the material on which the gauge is installed is more compliant that the gauge itself and is therefore more evident on e.g. on materials such as Epoxy (Espec = 3GPa versus Egauge = 180GPa) or other polymer materials typically utilized for composites. By the strain gauge according to the invention, the relatively long end loops have been found to result in a strain gauge where the strain field perturbations induced by the strain gauge on the material to be measured on are reduced considerably.

Numerical analyses on strain gauges according to the invention have shown that the elongated end loops of the strain gauge at both ends of the strain gauge and of a certain minimum length lead to considerably reduced strain field perturbations in both ends of the measuring part of the grid in the installed strain gauge, which is sometimes also referred to local reinforcement effects or edge effects.

Furthermore, this advantage is obtained for test specimens of a wide range of material and of different material stiffness.

Conventionally, all the parts of a strain gauge except the measuring grid sections themselves (such as the soldering tabs and the end loops) are preferably made as small as possible in order to make the overall size of the strain gauge correspondingly small. Contrary to this, the strain gauges according to the invention have shown to yield far more accurate results by extending the end loops far beyond what is required to merely interconnect the grid sections.

The relatively long end loops according to the invention have been shown by extensive numerical studies to result in a strain gauge yielding more precise measurements and with considerably reduced measurement errors or in-accuracies to a high degree independently of the material properties of the specimen which is tested. More precisely, the strain gauge design according to the invention reduces the measurement dependency on the stiffness of the test specimen significantly. This further leads to a significantly increased precision of the strain gauge when used on non-isotropic materials such as composites in general as for example fiber reinforced materials. The more anisotropic the test specimen, the more advantageous is the use of the strain gauge according to the invention compared to conventional strain gauges. As an example a unidirectional glass fiber composite has an axial stiffness on 35-45GPa in the fiber direction but a stiffness in 45 degree of less than 10GPa. The strain gauge according to the invention is seen to provide considerably more reliable and accurate measurements in this stiffness range.

Furthermore, the strain gauge according to the invention yields considerably more accurate measurements especially for more compliant materials. The strain gauge according to the invention thereby is especially advantageous for use in relation to measurements on materials of lower stiffness in all or some directions such as for example on most plastic materials or fiber reinforced composites. Further, as the improved strain gauge according to the invention is less stiffness dependent, is also obtained a more constant gauge factor or correction parameter during deformation. Hereby, the strain gauge according to the invention can be applied to obtain more accurate stress strain curves of test specimens of very different stiffness properties and also in the case of initially stiffer metallic materials. The reinforcement members of the strain gauge thus considerably reduce or eliminate an effect otherwise causing significant errors in material properties determination.

The extended length of the end loops of the strain gauges according to the invention has furthermore been shown to result in strain gauges yielding far more accurate results as compared to a conventional strain gauge, when applied to measure strain on components comprising a relatively thin outermost layer of a different material such as for example a coating layer. The improved strain measurements increase the thinner the superficial layer on the component. This means, that the strain gauge according to the invention are far more accurate when applied to e.g. composite components such as wind turbine blades or the like, as such components are both of a relatively compliant material, anisotropic, and often with an outermost thin protective layer such as a coating.

The carrier layer may comprise a film-type carrier layer, a substrate, or a foil, and may be formed in total or in part by a resin or a plastic material such as for example Polyamide.

The strain gauge may comprise further layers such as a backing layer, an adhesive layer, or a protective layer or coating on top of the measurement grid.

The measurement grid may be positioned or placed on the carrier layer by an adhesive or otherwise bonded to or deposited on the carrier layer. In an embodiment the measurement grid and or the reinforcement members are positioned on the carrier layer by etching techniques.

The measurement grid is meandering or arranged in a pattern such as to measure a deformation in an axial direction of the strain gauge as is commonly known from the manufacture of strain gauges. The measurement grid is formed from a number of grid sections extending primarily in the axial direction, placed side by side in an essentially parallel relationship or slightly zig-zagging, and connected in end loops at both ends of the measurement grid. The measurement grid may be formed from e.g. very thin wire or thin strips of metallic film deposited or otherwise positioned on the carrier layer. The wire width of conventional strain gauges may be in the range of 0.01 mm to 0.1 mm or even smaller. The grid sections are placed with gaps in between or a distance apart. The grid sections in the measurement grid may be placed uniformly in the entire or parts of the measurement grid. In an embodiment all the grid sections in the measurement grid are placed with approximately the same spacing. In another embodiment the strain gauge comprises a central portion wherein the grid sections are placed with approximately the same spacing. The end loops may attain different shapes such as rounded, rounded at one end, or rectangular.

The wire sections are conventionally placed as close as practically possible without touching in order to minimize the resistance changes of the measurement grid caused by other deformations than those in the axial direction, which are to be detected and measured. The grid sections may be placed with a wire distance or gaps in between in the range of 0.01-1.00 millimeters, such as for example in the range of 0.02-0.5 millimeters.

The advantageous effect of the elongated end loops as described in the previous has been demonstrated in numerous numerical studies both when compared to strain gauges with normal end loops and to strain gauges with a broad range of end loop lengths.

The end loops may advantageously be formed completely or in parts by the same material as the grid sections, which may be advantageous during manufacturing.

The end loops of increased length according to the invention work by increasing the stiffness at the end regions of the strain gauge acting as a sort of a reinforcement member. The length of the end loops is proportional to the ratio between a width of a grid section and the gap distance. Hereby, the reinforcing effect of the end loops is increased proportionally to the relative stiffness of the measuring part of the strain gauge. I.e. the effect of e.g. doubling the width of the wires (without changing the gap distance) is balanced by doubling the length of the end loops. Correspondingly, shorter end loops are needed for a strain gauge with relatively longer distances between the wires.

Numerical analyses have shown that an end loop length measured in millimeters of a factor times the ratio between a width of a grid section and the gap distance, wherein the factor is larger or equal to 1.5 yield strain gauges with the previously mentioned advantages. It has been observed that the length of the end loops in the axial direction affects the measurement accuracy of the strain and that an increased efficiency of the strain gauge is obtained for longer end loops. Furthermore, the numerical analyses have shown an approximate relationship between the end loops yielding markedly improved strain gauge measurements and the ratio between the width of the grid section and the gap distance times the above mentioned 1.5 and for a number of different strain gauge length. More precisely, for grid section lengths spanning from 1.5 mm to 10 mm. The effect is believed to be comparable for both longer and especially shorter strain gauges as the optimal end loop length is seen to be relatively independent of the absolute length of the measurement grid sections for a constant ratio of the wire width to the gap distance.

In an embodiment of the invention, the end loops extend a length in the axial direction of at least 1.5 mm. Hereby is obtained that the end loops act to reinforce the strain gauge such as to considerably reduce the local effects arising from the stiffness mismatch and thereby reducing the stiffness dependency of the strain gauge correspondingly.

In an embodiment, all the end loops of the measurement grid extend essentially the same length. Hereby a strain gauge is obtained of a uniform total length across the width of the strain gauge and which can be manufactured with only minor modifications to the manufacturing of a conventional strain gauge.

According to a further embodiment of the invention, the thickness of the end loops is essentially the same as the thickness of the measurement grid sections. This may be advantageous from a manufacturing view point, as the end loops can then advantageously be manufactured from the same foil or from a foil of the same type as the measurement grid sections or be applied by the same manufacturing processes. It is a further advantage that the end loops then do not increase the overall thickness of the strain gauge.

In an embodiment, at least some of the end loops extend a length in the axial direction of at least the ratio between the grid section width and the gap distance times a parameter, the parameter corresponding to 1.5 mm plus a percentage of the length of the grid sections, and wherein the percentage is in the range of 10-50%. The percentage may in an embodiment be in the range of 15-30%, such as for example of approximately 15%. It has been observed that the extension of the end loops in the axial direction affects the measurement accuracy of the strain and that an increased efficiency of the strain gauge is obtained for longer end loops. Furthermore, it has been observed that if longer measurement grid sections are chosen for the strain gauge, then correspondingly longer end loops are likewise to some extend more effective. A more precise strain gauge may thus be obtained when the lengths of the end loops in the axial direction are also chosen in dependency to some degree of the length of the measurement grid sections. The end loops have been seen to advantageously have a length given as a function of the length of the measurement grid sections, where the function is an approximately linearly increasing function.

In an embodiment of the invention, the the end loops extend a length in the axial direction in the range of 0.5- 5.0 mm for the ratio between a width of a grid section and the gap distance in the range of 0.9-1.1. In an embodiment the end loops extend a length in the axial direction in the range of 1.0-2.5 millimeters for the ratio between a width of a grid section and the gap distance in the range of 0.9-1.1

In an embodiment of the invention, the measurement grid has a length in the range of 1.00 – 15.00 mm , and wherein the end loops extend a length in the axial direction in the range of 0.5 - 5.0 mm, such as in the range of 1.0 - 4.5 mm, such as for example 1.5, 2.0, or 3.5 mm. The measurement grid in one embodiment has a length in the range of 1.25 - 10.00 mm, such as for example 1.50, 3.00, or 10.00 mm. In an embodiment the end loops extend a length in the axial direction in the range of 1.0 - 4.5 mm, such as for example 1.5, 2.0, or 3.5 mm. The above mentioned intervals of measurement grid length and end loop length may be combined.

A large number of numerical analyses were performed primarily based on numerical models of six commercially available strain gauges sold by the manufacturer HBM under the names

HBM Y series – S.G. Types 1-LY11-1.5/120, S.G. Types 1-LY11-3/120, and S.G. Types 1-LY11-10/120, and S.G. Types 1-LY11-1.5/350, S.G. Types 1-LY11-3/350, and S.G. Types 1-LY11-10/350 and based on the data of these strain gauges are as given by the manufacturer in the table in figure 27 and as measured with reference to the table in figure 28.

Based on these data, numerical tests were performed with different sizes of reinforcement member for the different sizes of the measurement grids of the strain gauges and their ratio between wire width and gap distance. Based on these analyses, the above mentioned dimensions for the end loop length were found to be especially advantageous.

In an embodiment, an end loop has a width in a direction transverse to the axial direction of approximately the gap distance plus two times a width of a grid section. Hereby, an end loop can be manufactured as simply an extension of the grid sections without any gap between. Such shape of the end loops simplifies the manufacturing of the strain gauge.

In an embodiment, at least some of the end loops have an essentially rectangular shape. Such shape of the end loops simplifies the manufacturing of the strain gauge.

In a further embodiment, the ratio between the end loop length and the grid section width is greater than 30. Sone strain gauges have been reported to have increased creep behaviour when the end loops are longer such as for exampleup to 8-10 times the wire width. However, the numerical analyses have shown that by even longer end loops, such that 30 times or more longer than the wire width, is obtained a strain gauge with the advantage of significantly lower measurement error over a wide range of material stiffness' from 4-200GPa as described in the previous.

In an embodiment, the strain gauge further comprises at least one soldering tab integrated with at least a portion of the measurement grid. Further, the soldering tab may be placed at one end of the strain gauge next to the end loops at that end. Hereby is obtained that the positioning of the soldering tab does not increase the overall length of the strain gauge any further.

The invention further relates to a method of manufacturing a strain gauge according to the above wherein the method comprises the steps of forming a meandering measurement grid of a number of grid sections extending essentially in an axial direction and placed side by side with gaps in between, interconnecting the measurement grid sections at their ends with end loops, wherein at least a plurality of the end loops at both ends of the measurement grid are formed to extend a length in the axial direction of a factor times the length of the grid sections, and times the ratio between a width of a grid section and the gap distance, wherein the factor is larger or equal to 30%, and positioning the measurement grid on a carrier layer,

The advantages hereof are further as described in the above in relation to the strain gauges according to the invention. Further, the strain gauge may hereby be manufactured simple and fast using conventional manufacturing techniques from strain gauge manufacturing. The measurement grid can for example be formed by deposition or etching.

Brief description of the drawings

In the following different embodiments of the invention will be described with reference to the drawings, wherein:

Fig. 1A shows one of the prior art strain gauges HBM Y series – S.G. Types 1-LY11-3/120 or S.G. Types 1-LY11-3/350 used for comparison to embodiments of strain gauges according to the invention,

Figs. 1B-C illustrate strain gauge for indication of different strain gauge parameters,

Figs. 2 and 3 show tables of the parameters of commercially available strain gauges HBM Y series – S.G. Types 1-LY11-1.5/350, 1-LY11-3/350, and 1-LY11-10/350 used as reference strain gauges for comparison to embodiments of strain gauges according to the invention,

Fig. 4 shows the measurement error of the prior art reference strain gauges as a function of test specimen stiffness,

Fig. 5 shows an embodiment of a strain gauge according to the invention with elongated end loops,

Fig. 6A shows the measurement error of the strain gauge of figure 5 for different lengths of the end loops and compared to the reference prior art strain gauge of figure 1A,

Fig. 6B shows an enlargement of the results of figure 6A,

Figs. 7A and B show the strain field around a strain gauge on a test specimen for a conventional strain gauge and a strain gauge according to the invention, respectively,

Fig. 8 shows how end loop length affects the strain distribution in a single wire of the grid in a strain gauges,

Figs. 9-10 show the measurement error of strain gauges with grid section lengths of 1.5 mm and 10 mm, respectively, and for different lengths of the end loops,

Figs. 11A and B show the measurement error of strain gauges with different wire width but constant ratio of wire width to wire gap distance, and for different lengths of the end loops,

Figs. 12A-C show the measurement error of strain gauges with a ratio of wire width to wire gap distance of 2, 1, and ½, respectively, and for different lengths of the end loops,

Fig. 13 shows the measurement error of a strain gauges of reduced out-of-plane thickness, and for different lengths of the end loops,

Figs. 14A and B show the measurement error of the strain gauge of figure 6 and modified to have a measurement grid length of 1.5 mm, respectively, and for different lengths of the end loops,

Fig. 15 shows the improved and optimal end loop length as a function of the length of the measurement grid,

Figs. 16A and B show the measurement error of the strain gauge of figure 6 as applied to a test specimen of three different thicknesses,

Figs. 17 and 18 show the measurement error of the strain gauge of figure 6 as applied to a test specimen with an outer thin layer of a polymer coating or a bi-axial material, respectively, and as a function of the thickness of the outer superficial layer, and

Fig. 19 shows an embodiments of a strain gauges according the invention with soldering tabs.

Detailed description of the drawings

Figures 1A and 1B show two typical strain gauges 100 as known from prior art and for measuring deformations in the axial directions 103 of the strain gauges. Figure 1B shows commercial available strain gauge as available from the company HBM and sold in different types with the parameters as given in figure 2. In figure 1C is further shown a schematic drawing of a strain gauge 100 indicating the different parts and characteristic parameters of a strain gauge. The strain gauges comprise a measurement grid 101 of a grid length 102, l_g, (called *a* in figures 1B and 2) and overall width *b*, and is placed on a carrier layer or foil (as indicated in figure 1B and with the dimensions *c* and *d*). The measurement grid 101 is meandering and comprises a number of interconnected grid sections 104 placed side by side with gaps 105 in between. The gap distance, wg, and the width of the grid sections or wire, *w* are indicated in figure 1C. The grid sections are connected in end loops 106 of a length, *l*, in the axial direction 103. The shape of the end loops may vary and in some cases be more rounded off than the rectangular shape indicated in figure 1C. The strain gauges all comprise solder tabs 107 which in these examples are both placed on one end of the strain gauge.

A large number of numerical tests were performed primarily based on numerical models of the three commercially available strain gauges sold by the manufacturer HBM under the names HBM Y series – S.G. Types 1-LY11-1.5/350 and S.G. Types 1-LY11-3/350, and S.G. Types 1-LY11-10/350, and variations hereof. Numerical analyses were also performed on strain gauges of the S.G. Types 1-LY11-XX/350 – series which only differ from the above -1-LY11-XX/120-series by the out-of-plane thickness of the measurement grid. The data of these strain gauges are as given by the manufacturer in the table in figure 2 and with reference to the schematic drawing in figure 1B. Additionally, the grid spacing or gap distance, *wg*, the width of the grid sections or wire width, *w*, and the end loop length, *l*, of these three strain gauges were measured. The measured values are given in the table in figure 3.

These three strain gauges 1-LY11-1.5-/350, 1-LY11-3-/350, and 1-LY11-10-/350 differ mainly by the length of the measurement grid of 1.5 mm, 30 mm, and 10 mm, respectively, and are used throughout the study as reference strain gauges and used in comparisons to embodiments of strain gauges according to the invention. These strain gauges were chosen because most common strain gauges have a grid length in the range from 1.5 mm to 10 mm.

In the numerical analyses, the strain gauges are made of Constantan (isotropic with a Elasticity module E=180 GPa and Poisson ration of 0.3), and the carrier layer has material properties corresponding to a Polyamide polymer (isotropic with a Elasticity module E=3.1 GPa and Poisson ration of 0.41) and with a thickness of 0.045 mm. The thickness of the measurement grid is 15 μm and the grid spacing or gap length between adjacent grid sections in the measurement grid is 0.03 mm, 0.03 mm, and 0.1 mm, for the three different strain gauges, respectively.

The performance of the prior art reference strain gauges of figures 1A, 2, and 3,, and of different measurement grid lengths L_g has been investigated and figure 4 shows the measurement error 200 of the strain gauges as a function of test specimen's Young Modulus (elasticity coefficients) $E_{material}$, 201 ranging from 1 GPa to 200 GPa. As can be seen from the graphs, all three strain gauges show very significant measurement errors especially for the lower stiffness coefficients. The more compliant the test specimen is, the more the measurement error increases. The measurement error is found using a gauge factor calibrated on a 200 GPa stiff material similar to what is done for the state-of-the-art strain gauges.

Note, that the numerical analyses shown here in figure 4 were performed on the strain gauges of figures 1A, 2 and 3, however with the solder tabs 107 removed for the purpose of reducing the size of the Finite Element model used in the analyses. Analyses of strain gauges with solder tabs were initially performed for comparison, demonstrating that the effect of removing the solder tabs 107 in the FEM were insignificant.

Figure 5 shows an embodiment of a strain gauge 100 according to the invention. The strain has the same material properties and measurement grid dimensions as the strain gauge of figure 1A and the HBM Y series S.G. Types 1-LY11-3/350 (second rows in the tables in figure 2 and 3) except for the length l, 500 of the end loops 106. The strain gauge according to the invention of figure 5 comprises end loops 106 interconnecting the grid sections or wires 104 which at both opposite ends of the measurement grid 101 extend a length l, 500 in the axial direction 103 of the strain gauge, wherein the end loop length is significantly longer than for conventional strain gauge designs. In this embodiment, the distance d is approximately the same as the grid spacing, but could in other embodiments be larger. The reinforcement members extend a length L_{reinf}, 302 in the axial direction.

Parameter studies have been conducted of the performance of the strain gauge with different length 500 of the end loops. Figure 6 shows the measurement error 200 of the strain gauge of figure 5 as a function of test specimen elasticity $E_{material}$ 201 and for different lengths of the end loops l, 500 of 0.3mm, 0.75mm, 1.0mm, 1.5mm, 2.0mm, and 2.75mm, respectively. The same results are shown in figure 6B zooming in on the lower measurement errors 200.

For comparison is also plotted the measurement error of the prior art strain gauge without elongated end loops of l=0.1mm of figure 1A. As can be seen from the curves, the strain gauge design with three times longer end loops than normal (l=0.3 corresponding to a ratio between the end loop length and the width of the wire of l/w=10) yield an improved performance however not significantly improved. Increasing the end loop length of the strain gauges, considerably more such as for example to 0.75mm (corresponding to 25% of the length of the grid section or a ratio between the end loop length and the width of the wire of l/w=25) yield, however significantly and considerably lower measurement errors especially for the more compliant test specimen materials. In this way the long end lops act to considerably reduce or remove the local effects from the stiffness mismatch between the strain gauge and the test specimen. The obtained strain gauges hereby may be used to obtain far more accurate strain or deformation measurements and with no or a reduced dependency of the stiffness or non-linearity of the tested material.

The numerical results showed that a small negative measurement error 200 occurred for the end loop length 500 increased above a certain limit. The optimal length 500 in this case was determined to be of approximately 2.00 mm corresponding to the second lowest curve 600 marked with rhombs.

Prior art strain gauges are known with elongated end loops such as suggested in EP 1033561 with the alleged effect of reducing the creep. However, these prior art strain gauges only show end loop lengths in the range of l/w=3 to l/w=10, where l/w is the ratio between the length of the end loop and the wire width. Compared to the strain gauge used in the numerical solutions of figures 5 and 6, these ratios would correspond to end loop lengths of l=0.09 and l=0.3, respectively. Such end loop lengths are seen to be too short to yield the desired effect of reduced measurement errors for a wide range of material stiffness's of the specimen on which the strain gauge is to measure.

Figure 19 shows an embodiment of such strain gauge according to the invention with a suggestion of how the soldering tabs 107 of the strain gauge could be placed relative to the measurement grid and the end loops. In this embodiment, the soldering tabs are placed next to the end loops at one end of the strain gauge whereby the soldering tabs need not make the strain gauge longer. In an embodiment, the two soldering tabs could be placed next to the end loops at opposite ends of strain gauge.

Figures 7A and B show the strain distribution in the specimen 700 underneath the strain gauge and in the strain gauge 100 itself, for the conventional strain gauge of figure 1A and for a strain gauge according to the invention of figure 5, respectively, and resulting from the numerical simulations of the present study. The specimen material is a relatively low stiffness material with a stiffness of E=10 GPa. The darker the colour, the lower strain.

From figure 7A can be seen how the mere presence of the strain gauge influences the strain distribution not only in the specimen beneath the strain gauge but especially inside the measurement grid of the strain gauge lowering the strains in a large portion of the measurement section considerably. This results in the strain gauge detecting and measuring lower strains than correct.

From figure 7B can be seen that the end loop reinforcement obtained by the significantly longer end loops yields an opposite strain gauge effect of larger strains in the ends of the measuring grid sections and levels up to the correct strain value in the major portion centrally in the grid. Hereby, the strain gauge experiences and measures an overall strain much closer to the strain actually imposed on the specimen. In other words, the specimen and the measurement wires are for the major part affected by the same strain.

Figure 8 shows the strain distribution 802 in a single wire of the grid as a function of the axial position 801 along the wire, and for different end loop lengths 500. The positions 800 mak the transition from the grid section to an end loop. These plots likewise illustrate how the longer end loops causes a limitation in the altered area underneath the end loops resulting in a more homogeneous and precise deformation in the wires. The longer the end loops, the more positive and even strain within the grid sections in the measurement grid.

The figures 9 and 10 show numerical results on strain gauges of a measurement grid length L_g, 102 of 1.5 mm and 10 mm, respectively, and corresponding to the prior art strain gauges of the types HBM Y series – S.G. Types 1-LY11-1.5/350 and S.G. Types 1-LY11-10/350 with data as in the first and third row in the figures 2 and 3, and for different end loop lengths 500. The results in figure 9 are thus for a strain gauge of half the length of the measurement grid length, lg, 102 (of 1,5 mm), whereas the strain gauge used for the results in in figure 10 has a relatively longer length of the measurement grid length, lg, 102 (of 10,0 mm). The plots in figures 9 and 10 show the measurement error 200 of the strain gauge for different lengths of the end loop length l, 500 and as a function of the stiffness $E_{material}$, 201 of the test specimen. The corresponding result for the reference prior art strain gauges with un-extended end loops as given by the data in figure 3 are also shown in the figures for comparison, as well as the relatively short end loop designs (of l=0,2 mm and l=0.8 mm, respectively corresponding to a ratio between the end loop length and the wire width of l/w=10). It is clear from the figure 9, that even though the absolute value of the measurement error 200 may be higher than for the LY-3 mm case (as shown in figure 6) the trend is the same. The optimal end loop length of the strain gauge seems to be obtained by an end loop length of approximately l=1.25 mm. Longer end loops appear to result in an under estimation of the Young’s modulus for some values of the test specimen stiffness and may therefore be less desirable in some applications.

For the strain gauge of the larger size with a measurement grid length, 102 of 10mm (S.G. Types 1-LY11-10/350 with longer end loops) the optimal end loop length 500 was determined to be of around 3.0 mm, as can be seen from the results of figure 10.

From figures 6, 8, and 9 can be seen that a much improved strain gauge design with considerably lower measurement error on a wide range of specimen's stiffness values from 3 to 200 GPa is obtained with end loop lengths from about l=1.0mm, l=1.0mm, and l=1.5mm, respectively.

In figures 11 A and B are shown numerical result on how changing the ratio between the wire width, w and the gap distance, w_{grid} affects the optimal end loop length of the strain gauge according to the invention. Figure 11A shows the results from the S.G. Types 1-LY11-3/350 strain gauge with and end loop length of l=2.0mm corresponding to the opptimal lenght as identified from figure 6. Figure 11B shows the measurement error, 200 for three different end loop lengths, l, 500 and with both the wire width and the gap distance halved. The ratio between the wire width, w and the gap distance is thereby kept constant, $w_{grid,}$, w/w_{grid} =1. The results indicate that the optimal end loop length does not change significantly when changing the wire width and the gap distance between the grid sections as long as the ratio between the wire width and the gap distance is the same.

On the other hand, the optimal end loop length changes when the ratio between the wire width and the gap distance is changed. This can be seen from the results in figure 12A-C which are conducted on the same S.G. Types 1-LY11-3/350 strain gauge only modified to have three different wire widths of w=0.06mm, 0.03mm, and 0.015mm, respectively. Hereby the ratios between the wire width and the gap distance for the three different plots are w/w_{grid} =2, 1, and 0.5, respectively. The plot in figure 12B is identical to the plot in figure 11A, only repeated for easier comparison.

Observing firstly the plot in Figure 12C, can be seen that decreasing the wire width leads to lower values of the measurement error for the 2.0 mm end loop (compared to the results of figure 12B), but however reduces the measurement error to negative values. The optimal value for the end loop length is therefore approximately l=1.0mm for w/w_{grid} = 0.5. Similarly. Figure 12A shows that the optimal end loop length is increased by increasing ratios. Due to limitations in the finite element model size, the optimal length was not established.

In general, the results indicate that the optimal length of the end loops is proportional to the ratios between the wire width and the gap distance. If the ratio is doubled, the optimal length of the end loops seems to be doubled as well. This observation is consistent with the observation that the elongated end loops act as reinforcement on the measurement area of the strain gauge. Therefore, if the stiffness of the strain gauge measurement area is increased (for example by increasing the wire width relative to the gap distance between the wires or by increasing the length), the stiffness of the reinforcement member formed by the end loop should be increased correspondingly to yield the same or comparable low measurement error.

Figure 13 show the results of changing the out-of-plane thickness of the strain gauge, i.e. of the grid sections as well as of the end loops. Increasing the length of the end loops results in a similar significant reduction of the measurement error 200 over a broad range of test specimen stiffness' 200 as seen in the previously discussed analyses. Further, comparing to figure 6, the optimal end loop length seems to be unchanged by the out-of-plane thickness of the strain gauge being reduced. Further, keeping the end-loop length constant but halving the strain gauge out-of-plane thickness (thickness) yields a little larger effect (i.e. a lower measurement error) on the more compliant test specimen materials.

Figures 14A and B show the effect of reducing the length of measurement grid, i.e. of the grid sections, l_g 102. The analyses perfomed on the S.G. Types 1-LY11-3/350 strain gauge were repeated with the grid section length reduced to l_g =1.5 mm, i.e. with 50%. The results in figure 14A are identical to the results in figure 6A only partly repeated here for ease of comparison. The results indicate a weak scaling of the optimal end loop length as a function of the length of the grid sections.

In figure 15 is shown the optimized end loop length l, 500 as a function of the length of the measurement grid l_{grid}, 102. Further is indicated a number of end loop lengths, which the numerical analyses have indicated to be significantly advantageous in reducing the measurement error, indicated with solid vertical bars. As indicated in the figure, the analysed strain gauges had different ratio of the wire width to the gap distance w/w_{gab} . The results show and demonstrate the general teaching that the optimized end loop length increases with the length of the measurement grid of the strain gauge and with the ratio of the wire width to the wire gap distance. In other words, more stiff end loop regions are advantageous to reduce the local effect with longer measurement grids of the strain gauge.

Figures 16A, B, and C show the even more advantageous effect of applying the strain gauges according to the invention with long end loops for thinner test specimens. In general, the thickness of the test specimen has a predominant influence on the reinforcement effect resulting from the use and application of a strain gauge on the test specimen during measurements. Figures 16A-C show the resulting measurement error for the strain gauge with a measurement length 201 of 3 mm (the S.G. Types 1-LY11-3/350 strain gauge) as reference or standard and as improved with end loop of a length of l=2.0 mm. The test specimen is modelled to have a Young's modulus of 10GPa. For the reference strain gauge with standard end loops, the results show no substantial difference between a test specimen with a thickness of 30 mm (figure 16C) an a thickness of 4mm (figure 16B). For a thickness of 2 mm (figure 16A), the measurement errors are higher.

The strain gauge design according to the invention with relatively long end loops of l=2.0 mm (compared to the length of the measurement grid sections of 3.0 mm) yield considerably lower measurement errors 200 for all three thicknesses of the test specimen and even for the thinner test specimen give strain measurements that are at least comparable to the ideally thick test specimen. Similar results were obtained with strain gauges of a measurement length of 1.5 mm and 10 mm. These results indicate that the advantageous effect of considerably reduced measurement error are also present for thinner test specimen or test samples.

Often, composite components comprise an outer relatively thin layer such as a polymer coating or another pliable material as for instance a biax. Such layer is sometimes referred to as a superficial layer and is often applied to protect the inner fibres of the composite structure. When a strain gauge is secured to the outer surface of such component for measuring, the superficial layer however affects the measurements of the strain gauge, even for thin outer layers.

Figures 17 and 18 show the results of a strain gauge according to the invention as applied to a test specimen comprising an outer superficial layer. The material of the main portion of the specimen has material properties of a UD Glass fibre.

In figure 17, the test specimen was modelled to comprise a very thin layer of material of E=3GPa to represent the glue underneath the strain gauge, or paint, or other chemical treatment to the surface. The thickness of this superficial layer was varied from 0 to 1.9 mm. The determined measurement errors, 200 are displayed in figure 17 as a function of the thickness of the coating layer and for the standard reference strain gauge design (S.G. Types 1-LY11-3/350 strain gauge) and as improved with end loops of lengths of l=1.5 and 2.0 mm. The results clearly demonstrate significantly lower measurement errors with the strain gauges according to the invention and far more precise results especially for the more thick coating layer.

In figure 18, the test specimen was modelled to comprise a very thin layer of material of E=10GPa to represent a bi-axial layer placed as the outermost layer of the component. The thickness of this superficial layer was varied from 0 to 3 mm. The determined measurement errors, 200 are displayed in figure 18 as a function of the thickness of the coating layer and for the standard reference strain gauge design (S.G. Types 1-LY11-3/350 strain gauge) and as improved with end loops of lengths of l=2.0 mm. As with the coating layer of figure 17, the results clearly demonstrate significantly lower measurement errors with the strain gauges according to the invention and far more precise results especially for the more thick superficial layer.

While preferred embodiments of the invention have been described, it should be understood that the invention is not so limited and modifications may be made without departing from the invention. The scope of the invention is defined by the appended claims, and all devices that come within the meaning of the claims, either literally or by equivalence, are intended to be embraced therein.

CLAIMS

1. A strain gauge comprising a carrier layer and a meandering measurement grid positioned on the carrier layer, wherein the measurement grid is arranged such as to measure a deformation in an axial direction of the strain gauge, wherein the measurement grid comprises:

- a number of measurement grid sections extending essentially in the axial direction and being placed side by side with gaps in between, and
- a number of end loops interconnecting the measurement grid sections at their ends,

wherein at least a plurality of the end loops at both ends of the measurement grid extend a length in the axial direction in millimetres of a factor times a ratio between a width of a grid section and the gap distance, wherein the factor is larger or equal to 1.5.

2. A strain gauge according to claim 1, wherein the end loops extend a length in the axial direction of at least 1.5 mm.

3. A strain gauge according to any of the preceding claims wherein all the end loops of the measurement grid extend approximately the same length.

4. A strain gauge according to any of the preceding claims wherein the thickness of the end loops is approximately the same as the thickness of the measurement grid sections.

5. A strain gauge according to any of the preceding claims wherein at least some of the end loops extend a length in the axial direction of at least the ratio between the grid section width and the gap distance times a parameter, the parameter corresponding to 1.5 mm plus a percentage of the length of the grid sections, and wherein the percentage is in the range of 10-50%.

6. A strain gauge according to any of the preceding claims wherein the end loops extend a length in the axial direction in the range of 0.5- 5.0 mm such as in the range of 1.0-2.5 millimeters for the ratio between a width of a grid section and the gap distance in the range of 0.9-1.1.

7. A strain gauge according to any of the preceding claims wherein the measurement grid has a length in the range of 1.00 – 15.00 mm, and wherein the end loops extend a length in the axial direction in the range of 0.5 - 5.0 mm.

8. A strain gauge according to any of the preceding claims wherein an end loop has a width in a direction transverse to the axial direction of approximately the gap distance plus two times a width of a grid section.

9. A strain gauge according to any of the preceding claims, wherein a ratio between the end loop length and the grid section width is greater than 30.

10. A strain gauge according to any of the preceding claims further comprising at least one soldering tab integrated with at least a portion of the measurement grid .

11. A strain gauge according to claim 9 wherein the soldering tab is placed at one end of the strain gauge next to the end loops at that end.

12. A strain gauge according to any of the preceding claims wherein at least some of the end loops have an approximately rectangular shape.

13. A method of manufacturing a strain gauge according to any of claims 1-12 comprising the steps of forming a meandering measurement grid of a number of grid sections extending essentially in an axial direction and placed side by side with gaps in between, interconnecting the measurement grid sections at their ends with end loops, wherein at least a plurality of the end loops at both ends of the measurement grid are formed to extend a length in the axial direction in millimetres of a factor times a ratio between a width of a grid section and the gap distance, wherein the factor is larger or equal to 1.5, and positioning the measurement grid on a carrier layer.

14. A method of manufacturing a strain gauge according to claim 13, wherein the measurement grid is formed by deposition or etching.

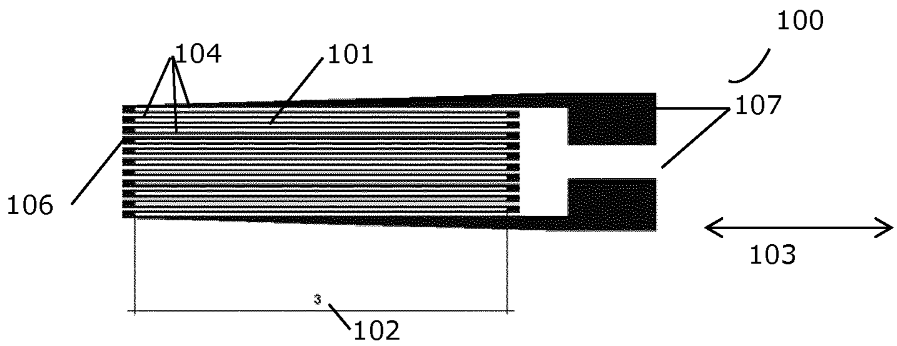

Fig. 1A

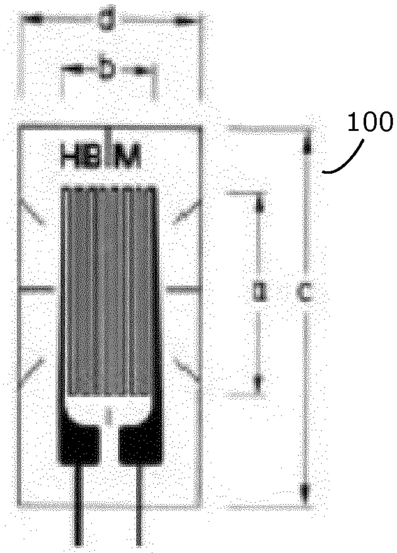

Fig. 1B

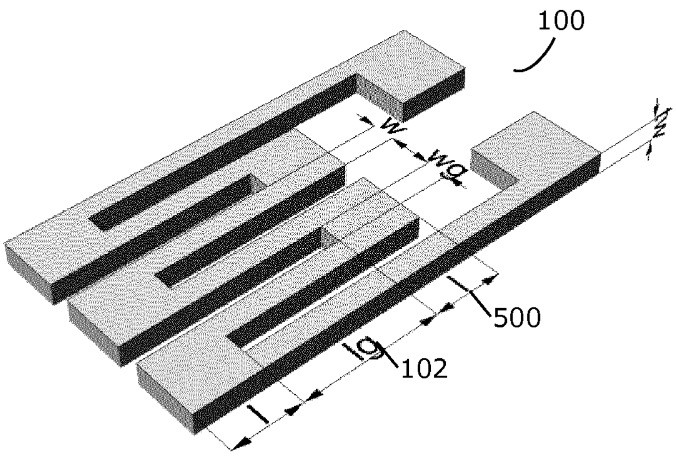

Fig. 1C

S.G. Type	a [mm]	b [mm]	c [mm]	d [mm]	Grid [mm]	Foil [mm]
1-LY11-1.5-/350	1.5	1.2	6.5	4.7	0.005	0.045
1-LY11-3-/350	3	1.6	8.6	4.5	0.005	0.045
1-LY11-10-/350	10	4.6	18.5	9.5	0.005	0.045

Fig. 2

S.G: Type	Grid spacing [mm]	Wired width [mm]	End-Loops length [mm]
1-LY11-1.5-/350	0.03	0.02	0.07
1-LY11-3-/350	0.03	0.03	0.1
1-LY11-10-/350	0.1	0.08	0.3

Fig. 3

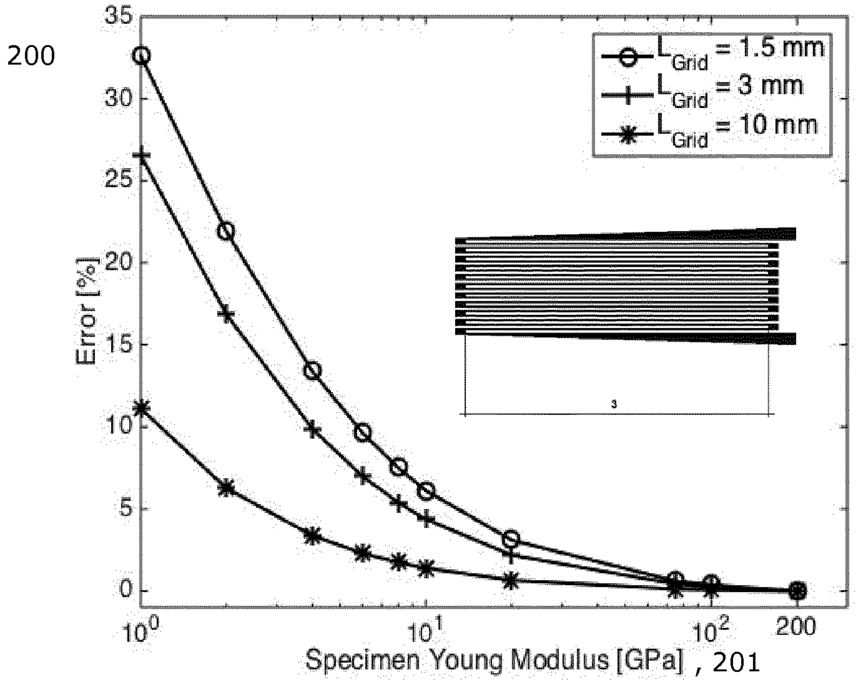
200
35
30
25
20
15
10
5
0
Error [%]
L Grid = 1.5 mm
L Grid = 3 mm
L Grid = 10 mm
3
10^0
10^1
10^2
200
Specimen Young Modulus [GPa] , 201

Fig. 4

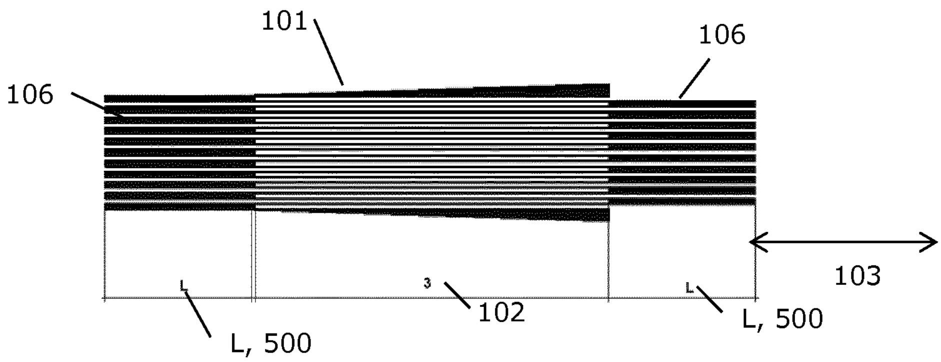
101
106
106
103
L
3
L
102
L, 500
L, 500

Fig. 5

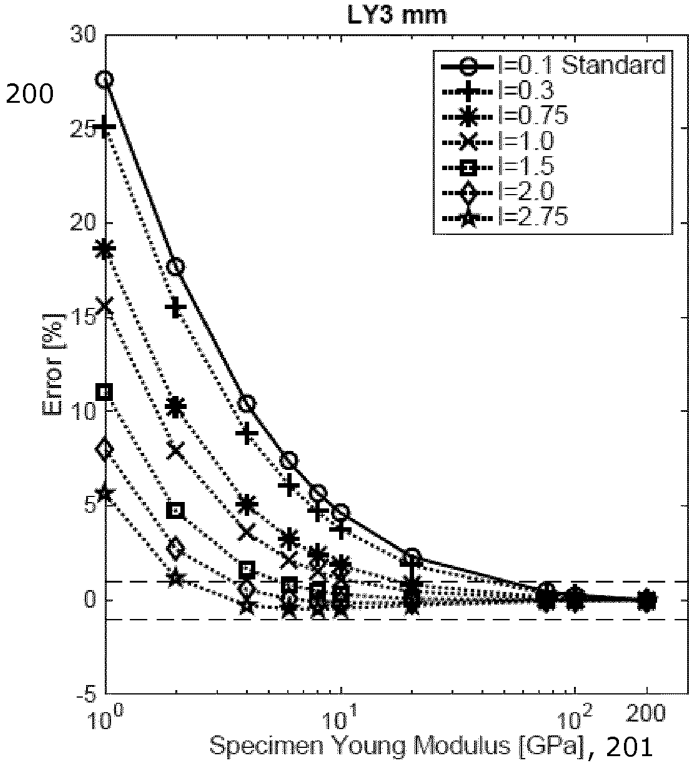
LY3 mm
200
I=0.1 Standard
I=0.3
I=0.75
I=1.0
I=1.5
I=2.0
I=2.75
Error [%]
30
25
20
15
10
5
0
-5
10^0
10^1
10^2
200
Specimen Young Modulus [GPa], 201

Fig. 6A

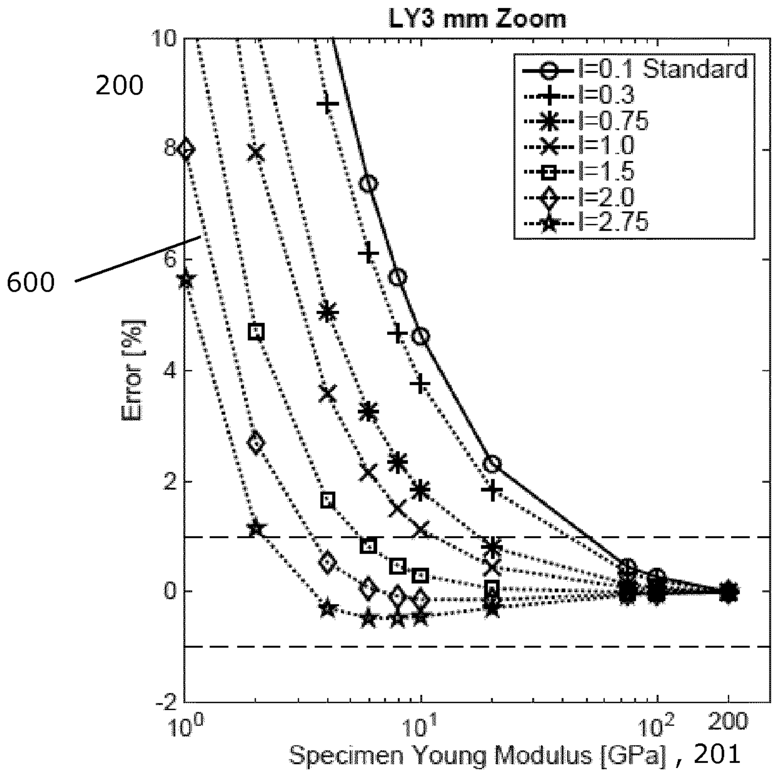
LY3 mm Zoom
200
600
I=0.1 Standard
I=0.3
I=0.75
I=1.0
I=1.5
I=2.0
I=2.75
Error [%]
10
8
6
4
2
0
-2
10^0
10^1
10^2
200
Specimen Young Modulus [GPa] , 201

Fig. 6B

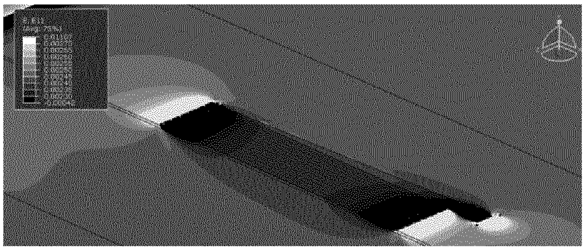

Fig. 7A

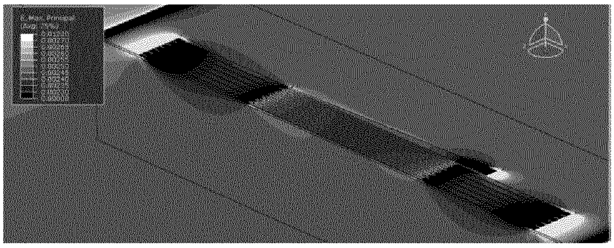

Fig. 7B

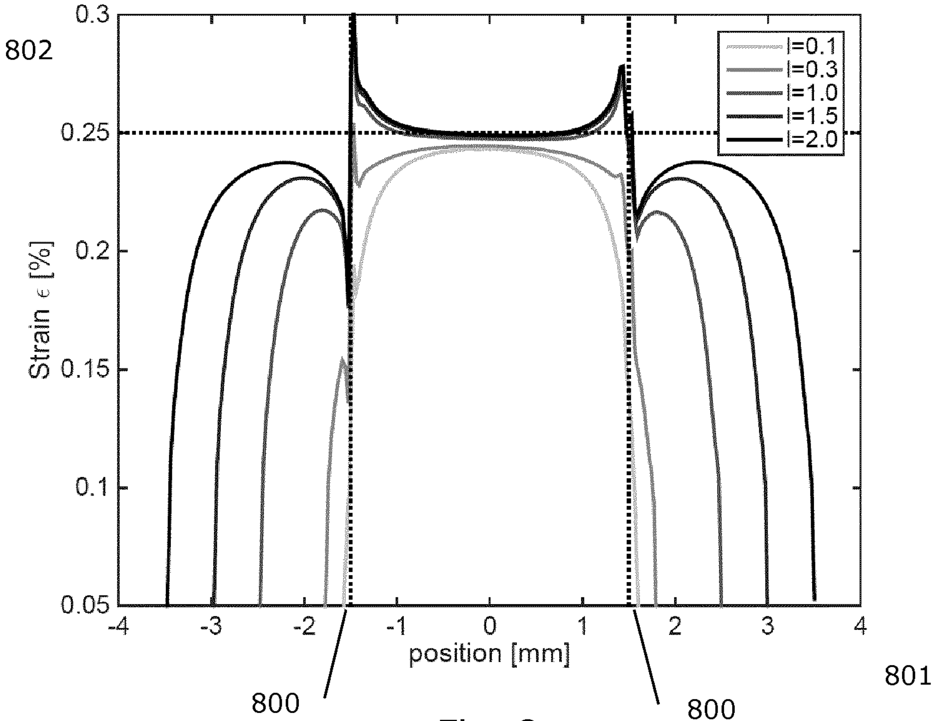

Fig. 8

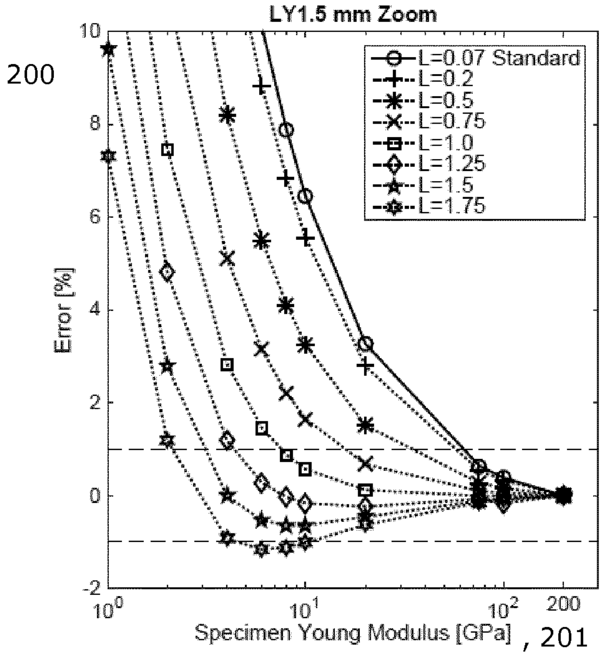
LY1.5 mm Zoom
200
L=0.07 Standard
L=0.2
L=0.5
L=0.75
L=1.0
L=1.25
L=1.5
L=1.75
Error [%]
Specimen Young Modulus [GPa]
, 201

Fig. 9

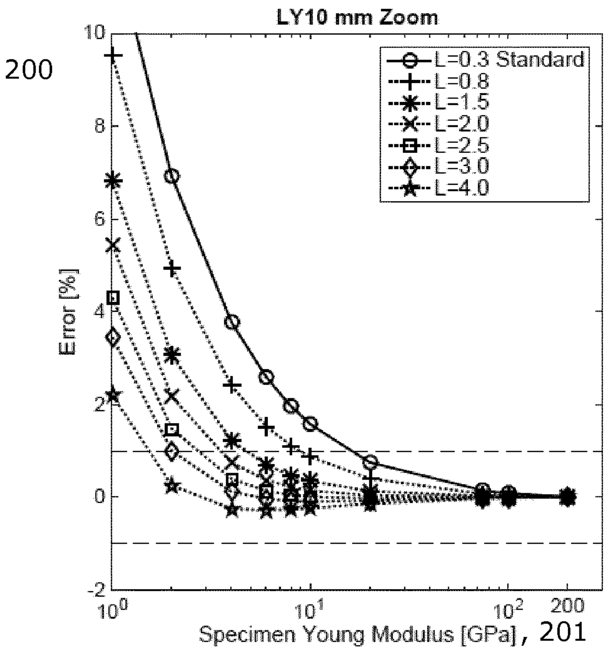
LY10 mm Zoom
200
L=0.3 Standard
L=0.8
L=1.5
L=2.0
L=2.5
L=3.0
L=4.0
Error [%]
Specimen Young Modulus [GPa]
, 201

Fig. 10

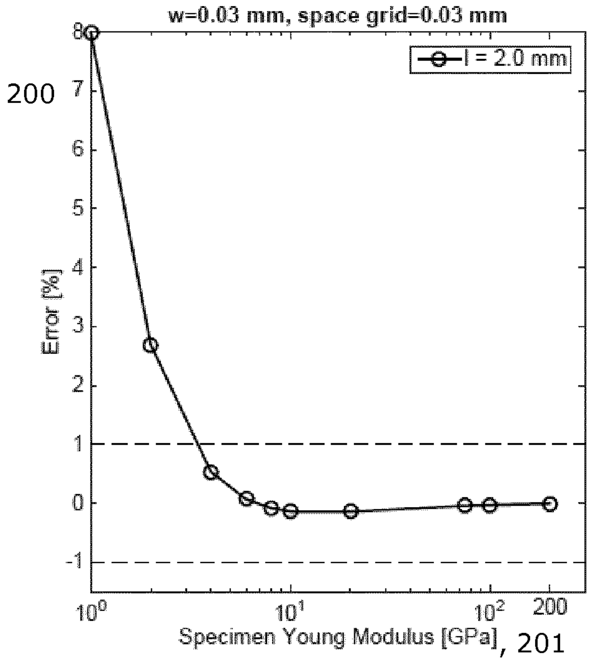

Fig. 11A

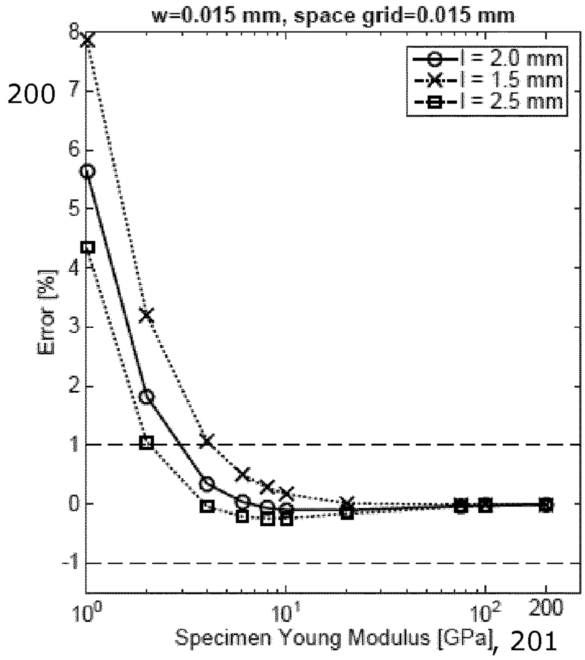

Fig. 11B

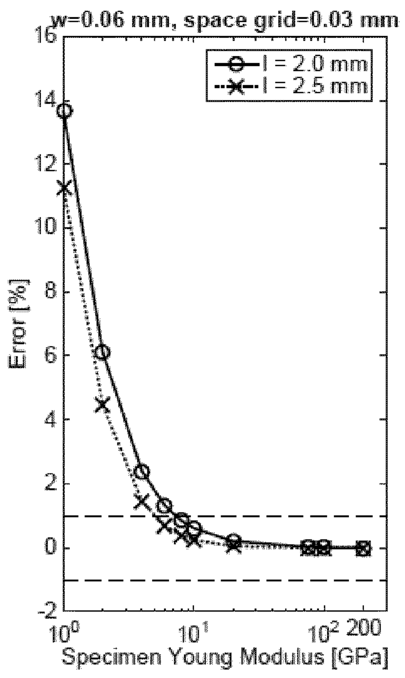

Fig. 12A

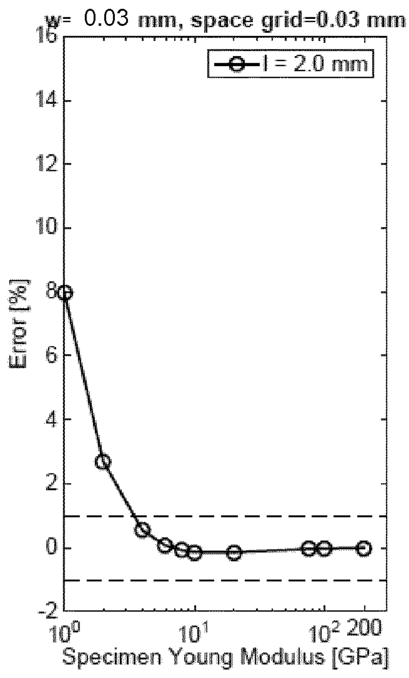

Fig. 12B

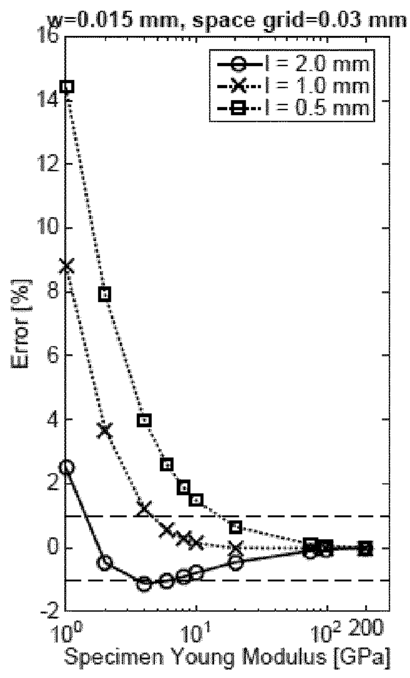

Fig. 12C

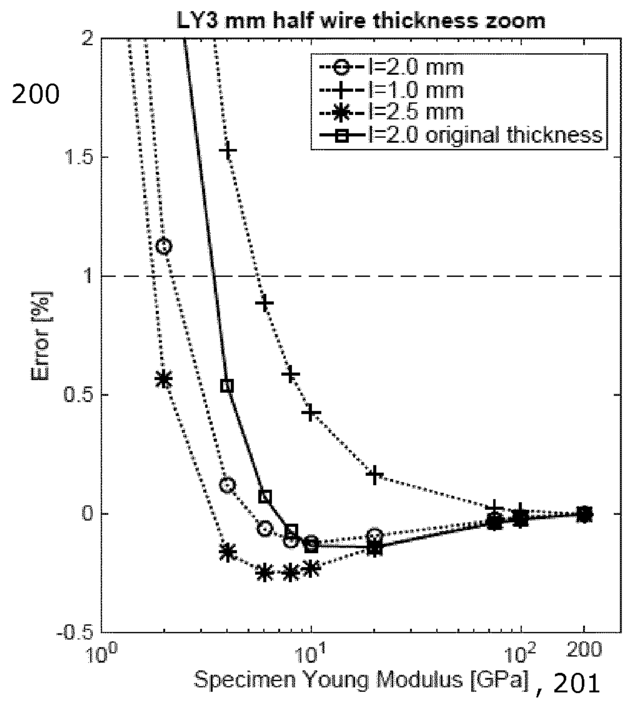

Fig. 13

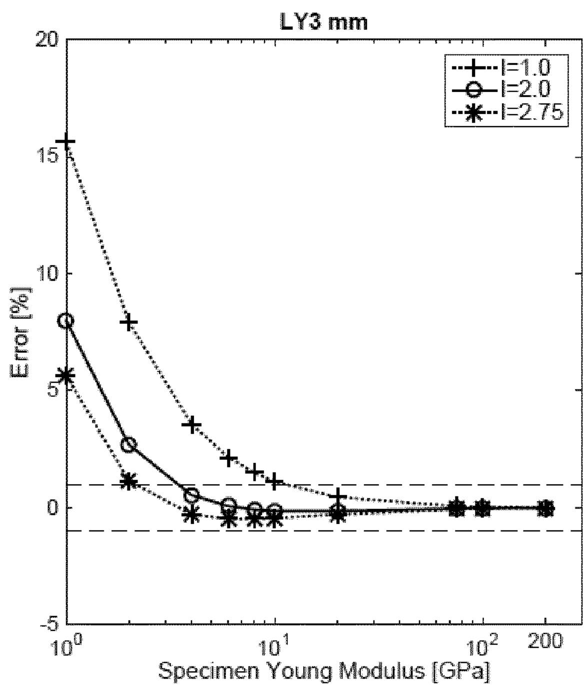

Fig. 14A

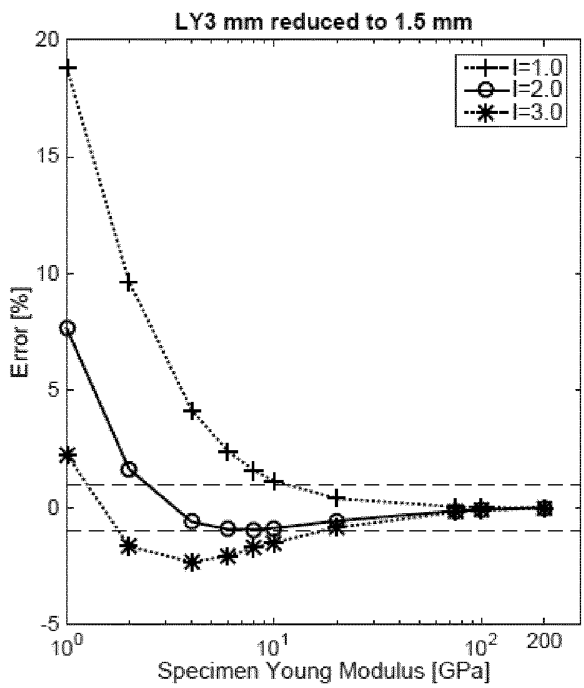

Fig. 14B

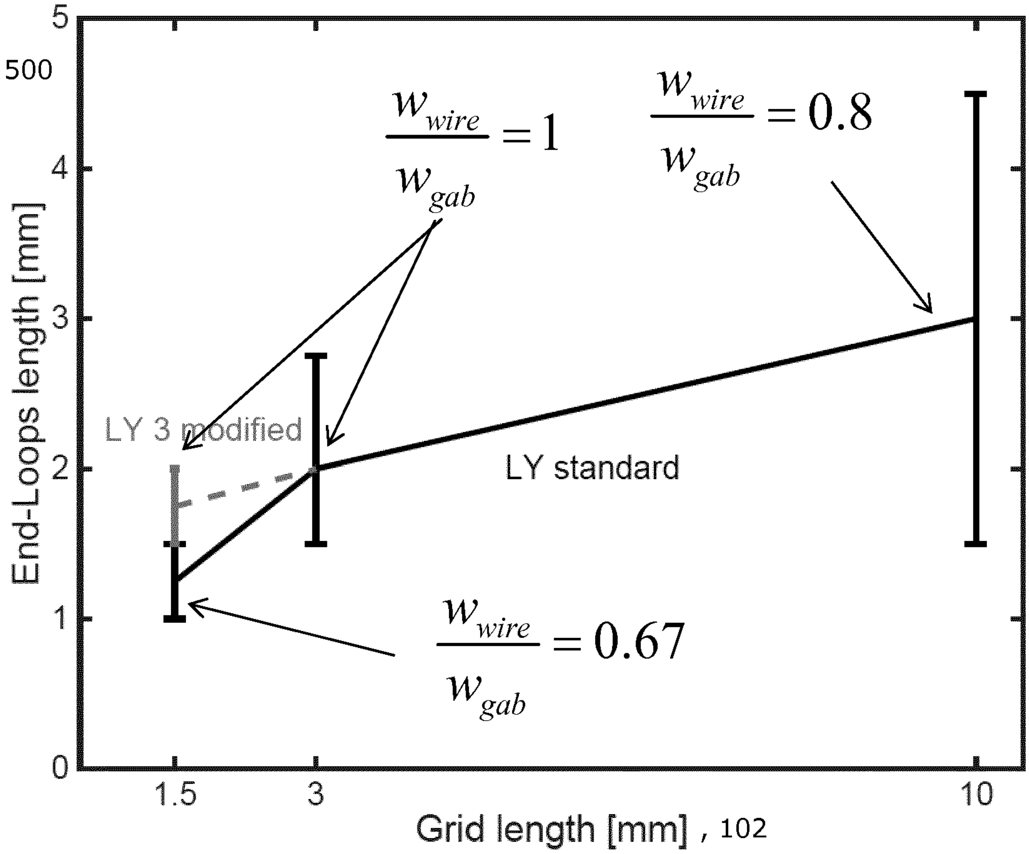
500
5
4
3
2
1
0
End-Loops length [mm]
$\frac{w_{wire}}{w_{gab}} = 1$
$\frac{w_{wire}}{w_{gab}} = 0.8$
LY 3 modified
LY standard
$\frac{w_{wire}}{w_{gab}} = 0.67$
1.5
3
10
Grid length [mm] , 102

Fig. 15

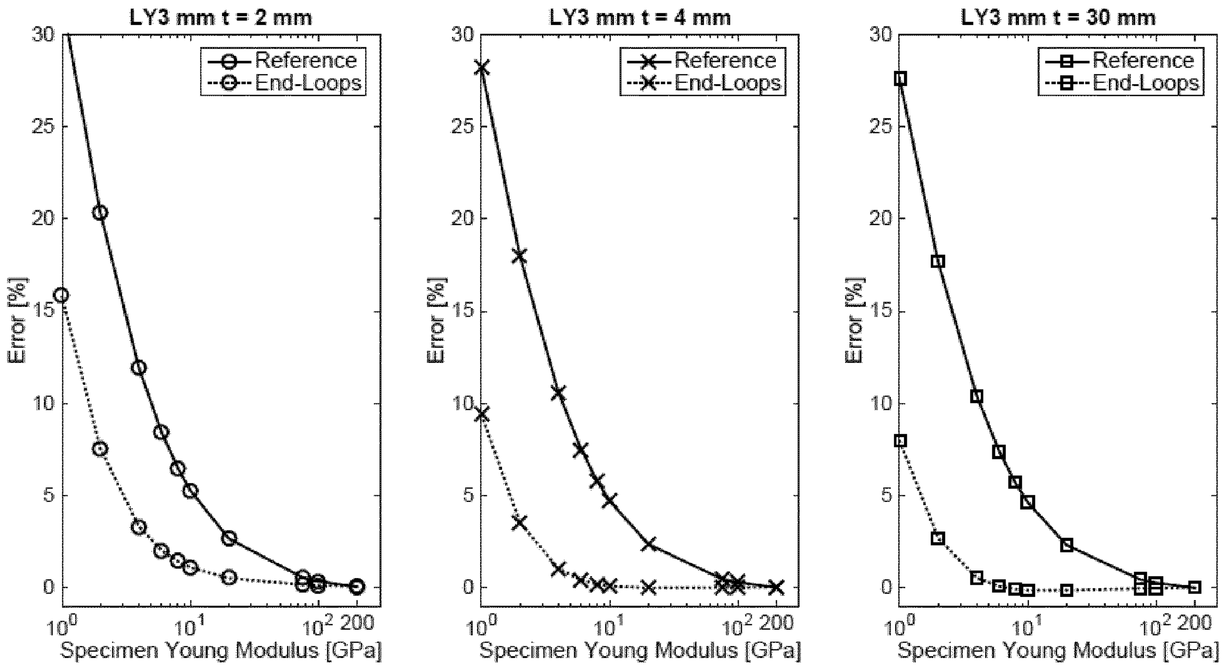

Fig. 16A Fig. 16B Fig. 16C

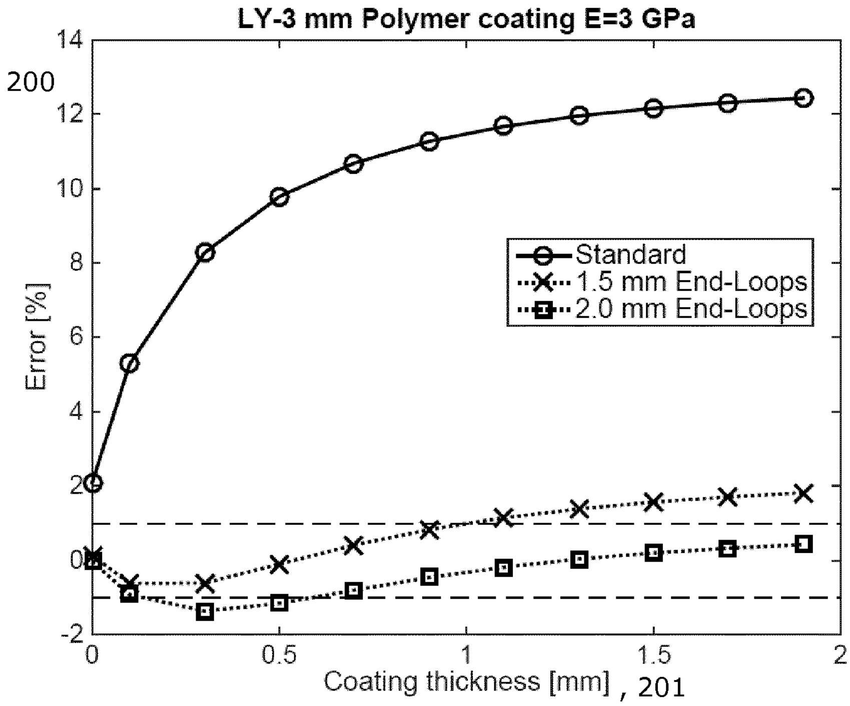
LY-3 mm Polymer coating E=3 GPa
200
Error [%]
Standard
1.5 mm End-Loops
2.0 mm End-Loops
Coating thickness [mm] , 201
14
12
10
8
6
4
2
0
-2
0
0.5
1
1.5
2

Fig. 17

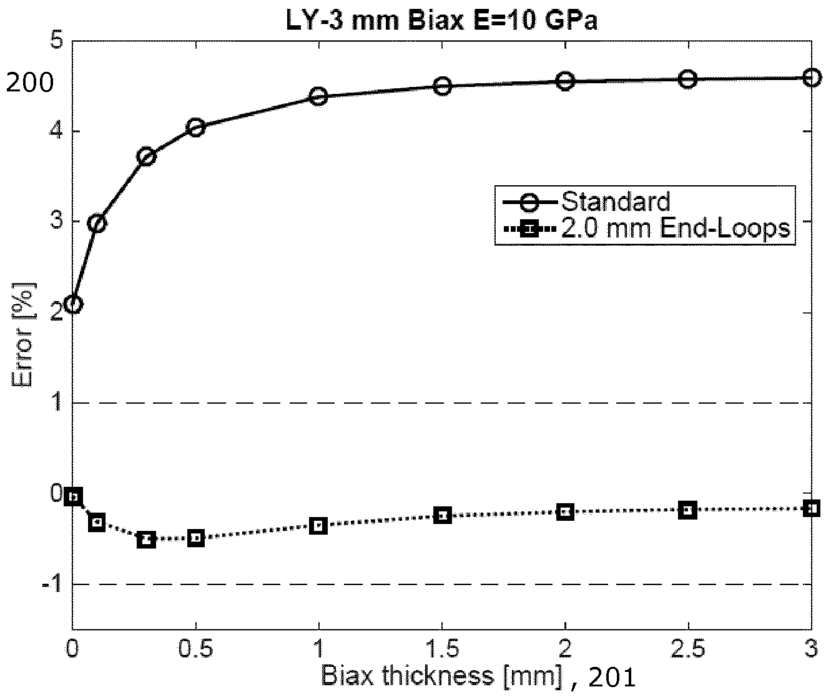
LY-3 mm Biax E=10 GPa
200
Error [%]
Standard
2.0 mm End-Loops
Biax thickness [mm] , 201
5
4
3
2
1
0
-1
0
0.5
1
1.5
2
2.5
3

Fig. 18

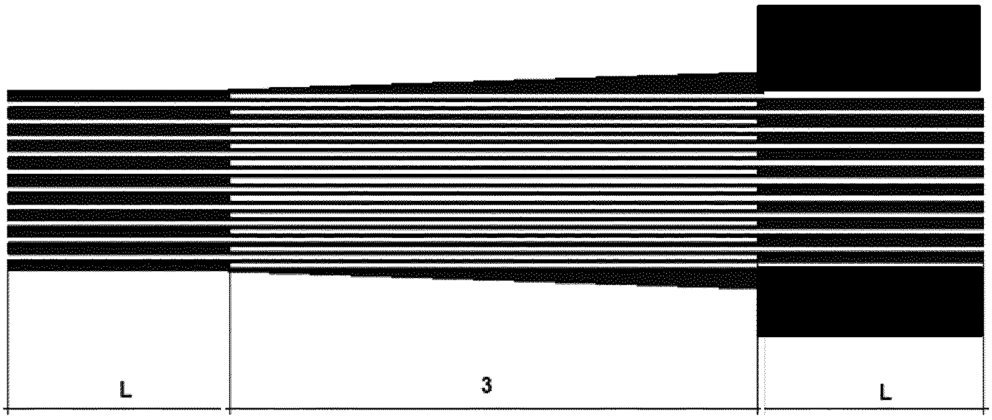

Fig. 19

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/066604

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01B7/16 G01L1/22
ADD.

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)
G01L G01B

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 practicable, 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 1 033 561 A2 (HBM WAEGETECHNIK GMBH [DE]) 6 September 2000 (2000-09-06) cited in the application the whole document	1-14
X	JP 2006 030163 A (TANITA SEISAKUSHO KK) 2 February 2006 (2006-02-02) abstract; figures	1-14

☐ Further documents are listed in the continuation of Box C.

☒ 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 application or patent 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
24 August 2016	01/09/2016

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, Fax: (+31-70) 340-3016	Stavroulis, Stefanos

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/066604

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 1033561 A2	06-09-2000	AT 221649 T	15-08-2002
		DE 19909042 A1	07-09-2000
		DK 1033561 T3	11-11-2002
		EP 1033561 A2	06-09-2000
		ES 2177485 T3	16-12-2002
JP 2006030163 A	02-02-2006	NONE	