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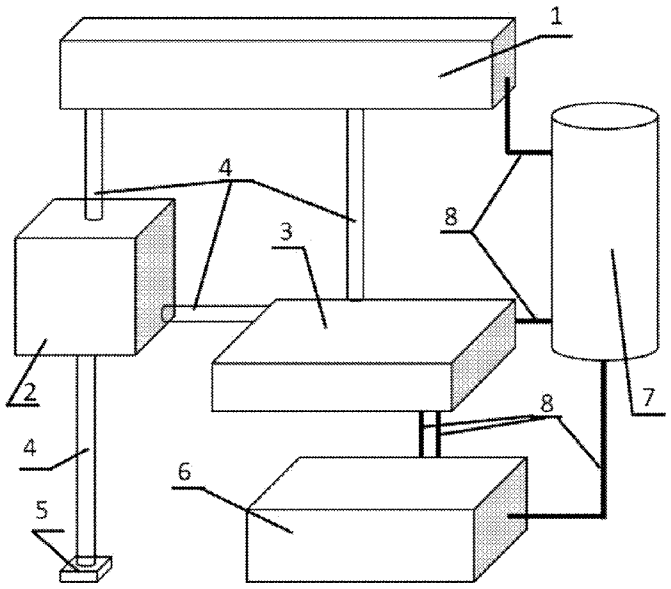
(54) **Title:** RADIO SENSOR FOR DETECTING MATERIAL DEFECTS

[Fig. 1]



(57) **Abstract:** The object of the invention is a radio sensor for detecting material defects in 3D printer prints comprising a signal generator, a signal measurement module and a microcontroller, characterised in that the signal generator (1) with a frequency of 433 MHz has two signal output ports, one of which is connected to a directional coupler (2), and the second port is connected to a signal measurement module (3), and furthermore the directional coupler (2) is connected to a probe (5) and to the signal measurement module (3), wherein the connections of the elements (1, 2, 3, 5) are made by means of a coaxial cable (4), while the signal measurement module (3) is connected by means of a cable (8) to a microcontroller (6), wherein the sensor is powered by a power supply (7) connected by cables (8) to the signal generator (1), the signal measurement module (3) and to the microcontroller (6). The subject of the invention is also a method of detecting material defects in 3D printer prints carried out by the sensor according to the invention.

WO 2024/253549 A1

[Continued on next page]

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Description

Title of Invention : Radio sensor for detecting material defects

Technical Field

[0001] The object of the invention is a radio sensor for detecting material defects.

Background Art

[0002] In the state of the art, solutions are known that allow for detecting material defects created during 3D printing. For example, in the descriptions of patent applications US20150045928A1, US20160368220A1 and WO2017087451A1 methods of controlling the printing of samples are disclosed. The solutions presented therein use optical scanning and comparisons of taken photos with a previously prepared sample using intelligent algorithms.

[0003] The Chinese patent application CN105619818A describes a device for detecting errors in the 3D printing process using an acoustic sensor. In turn, the Chinese patent application CN104309130A presents a solution for a 3D printer with an intelligent material feeder and a control system for the filament feeder exiting the nozzle, which is based on an electric induction charge sensor. The system allows for detecting defects related to the nozzle being clogged by material, and the invention does not use microwave radiation.

[0004] In the publication by Dmitry Isakov et al. entitled: “A Split Ring Resonator Dielectric Probe for Near-Field Dielectric Imaging”, May 2017 Nature Scientific Reports 7(1):2038 a probe with a resonator for 2D surface mapping and imaging of relative dielectric permittivity for the characterization of composite materials is presented. This solution uses the measurement of the dielectric properties of the surface of composite materials and disturbances in the signal transmission through the sample, and not changes in the reflection coefficient.

[0005] Commercial solutions using artificial intelligence algorithms to take pictures of samples and automatically detect potentially incorrect print elements are also available in the prior art, offered for example by the company PrintNanny.

Technical Problem

[0006] The inventors conducted research on sensors for detecting defects in 3D printing. Patent application P.445179 discloses a microwave sensor constructed from a vector network analyser connected to a coaxial probe by means of a microwave coaxial cable of the type RG142.

[0007] A prototype of a microwave sensor was also described in the preprint of the publication by Ślot, Maciej et al. entitled: “Non-Contact Microwave Sensor for 3d Printing Quality Control.”, http://dx.doi.org/10.2139/ssrn.4655382, 2003. A prototype of a microwave sensor that allows for the detection of defects in a sample by examining the reflection of a wave with a frequency of 1.32 GHz from the sample was presented there. The prototype contains a vector analyser, which is an element that transmits and analyses the signal.

[0008] In the course of further research work, the present inventors aimed to optimize the cost of the sensor and to improve the analysis of data generated by the sensor.

[0009] The technical problem of the present invention is to provide a sensor for detecting material defects in prints of 3D printer, which at the same time enables detecting inhomogeneity in doping, wherein the sensor is made of cheap and commonly available components while maintaining measurement sensitivity comparable to commercial solutions.

Solution to Problem

[0010] The object of the invention is a radio sensor for detecting material defects in prints of 3D printer comprising a signal generator, a signal measurement module and a microcontroller, characterized in that the 433 MHz signal generator has two signal output ports, one of which is connected to a directional coupler and the other port is connected to the signal measurement module, and furthermore the directional coupler is connected to a probe and to the signal measurement module, wherein the connections of these elements are made by means of a coaxial cable, while the signal measurement module is connected by a cable to a microcontroller, wherein the sensor is powered by means of a power supply connected by cables to the signal generator, the signal measurement module and to the microcontroller.

[0011] In the radio sensor according to the invention, the probe consists of a base made of a conductive material and located centrally in the base a copper wire with a diameter of 0.5-1 mm, which is covered with Teflon insulation. The shape and dimensions of the probe base can be freely shaped, therefore it is easily scalable. Preferably, the probe base has the shape of a cuboid with a square base and dimensions of 6.3 mm x 6.3 mm and a height of 1.5 mm.

[0012] Furthermore, the probe is detachable connected to the directional coupler, thus ensuring the possibility of conveniently positioning the probe relative to the sample of the tested material and then connecting it to the rest of the sensor.

[0013] In the probe according to the invention, the connections between the port, directional coupler, probe and signal measurement module are advantageously made by means of coaxial cable type RG316.

[0014] In the solution according to the invention, a signal generator is used, which emits a signal of the same frequency through each of the ports, respectively through a directional coupler to the probe and to the signal measurement module, therefore a vector analyser is not used to generate and analyse the signal, as shown in the prototype developed earlier. In addition, in the present invention, a radio signal generator with a frequency of 433 MHz is used, and not a microwave signal generator with a frequency of 1.32 GHz. Thanks to this, it was possible to make the sensor from cheaper and more available components.

[0015] Furthermore, the use of a probe instead of an antenna or waveguide in the solution according to the invention makes the sensor cheaper to make. Antennas or waveguides acting as an antenna are devices intended for long-distance wave communication and transmits waves effectively to the far field and it would not be possible to use them in the solution according to the invention, because at a frequency of 433 MHz the resolution of a single pixel would be counted in meters. Additionally, the antenna, also a directional antenna, collects part of the waves from the environment, therefore the measurement using such an antenna would be strongly disturbed.

[0016] Another object of the invention is a method of detecting material defects in 3D printouts carried out by means of a sensor according to the invention, which is characterized in that the probe is placed at a certain distance from the surface of

the tested material, then a signal with a frequency of 433 MHz is emitted using a signal generator, which is transmitted to the probe through a first port using a directional coupler, and through a second port, the signal is transmitted to the signal measurement module, then the signal emitted from the probe, after contacting with the surface of the tested material, is reflected from it and returns to the probe, and then through the directional coupler is transmitted to the signal measurement module. Then, using a microcontroller, the phases of the wave signals generated directly from the generator and the reflected wave coming from the probe are analysed, comparing them with each other, wherein the microcontroller and the signal measurement module and the signal generator are powered by a power supply, which supplies a current with a constant voltage of 5V.

[0017] In the method according to the invention, the probe is placed at a distance of no more than 0.1-1 mm from the surface of the tested material, preferably at a distance of 0.1 mm. The design of the sensor and its small dimensions also provide the possibility of analysing layers up to 0.5 mm into the surface for materials with a low dielectric constant such as plastic or doped materials. Thanks to this, the solution according to the invention provides measurement of print defects not only on the surface, but also slightly below the surface of the print in an accurate manner, without noise from the surroundings.

[0018] The signal measurement module compares the phases of both signals, while the microcontroller detects the phase differences. Therefore, if during scanning of the sample of the tested material there are phase differences of e.g. 10 degrees +/- 0.5 degrees and suddenly during the measurement the phase difference is different, it means that there is a defect in the sample of the tested material in a given measurement location, because the signal was reflected in a different phase than in the environment. Phase differences measured in individual locations of the tested material indicate the inhomogeneity of its surface or surface layers, which may result from a print defect or from a different level of material doping.

[0019] In the method according to the invention, the measurement of the uniformity of the print surface is carried out during the 3D print. Thanks to this, the correctness of the print can be continuously monitored, especially since the small

size of the probe allows for obtaining a millimetre resolution of the sample measurement.

[0020] The method according to the invention ensures control of the print quality and identification of places where defects or inhomogeneity occur, regardless of the printing method, whether it is a print in the FDM (Fused Deposition Modelling) technology or a print in powder technologies.

Brief Description of Drawings

[0021] The radio sensor for detecting material defects is explained in more detail in an example of its embodiment, in the drawing, in which:

Fig.1

[0022] shows its schematic diagram,

Fig.2

[0023] shows the sensor in an isometric view.

Description of Embodiments

[0024] The sensor comprises a signal generator 1 equipped with two parallel ports that simultaneously emit a signal in the form of waves at a frequency of 433 MHz, wherein one port is connected to a directional coupler 2 and the second port is connected to a signal measurement module 3, and furthermore, the directional coupler 2 is detachable connected to a probe 5 and to a signal measurement module 3, wherein the connections of the elements 1, 2, 3, 5 are made by means of a coaxial cable 4 of the RG316 type, while the signal measurement module 3 is connected by means of a wire 8 to a microcontroller 6, wherein the sensor is powered by means of a power supply 7 emitting a current with a constant voltage of 5 V and connected by wires 8 to the signal generator 1, the signal measurement module 3 and to the microcontroller 6. The probe 5 consists of a base 5a made of brass in the shape of a cuboid with dimensions of 6.3 mm x 6.3 mm and a height of 1.5 mm, inside which is placed a central copper wire 5c with a diameter of 1 mm, which is covered with 5b Teflon insulation.

[0025] Detection of material defects in 3D printer prints using the sensor described above is carried out in the following manner. The probe 5 is placed at a distance of 1 mm from the surface of the material being tested, then an electromagnetic

wave signal with a frequency of 433 MHz is emitted using the signal generator 1, which is transmitted through the first port to the probe 5 using the directional coupler 2, and through the second port the signal is transmitted to the signal measurement module 3. The signal emitted from the probe 5, after contacting the surface of the tested material, is reflected from it. Using microcontroller 6, the phase of the generated wave and the reflected wave is analysed during scanning of the sample of the tested material. During scanning, phase differences occur at the level of e.g. 10 degrees +/- 0.5 degrees, which means a homogeneous structure of the printout. If during scanning a significant deviation in the phase difference between the generated wave and the reflected wave occurs, this indicates the occurrence of a defect in the sample of the tested material on its surface or in the subsurface layer, because the signal was reflected in a different phase than in the surroundings.

Reference Signs List

[0026]

1- generator,

2- directional coupler,

3- radio signal phase measurement module,

4- coaxial cables,

5- probe,

5a- probe ground,

5b- Teflon insulation,

5c - copper wire

6- microcontroller,

7- power supply,

8- wires.

Claims

[Claim 1] A radio sensor for detecting material defects in 3D printer prints comprising a signal generator, a signal measurement module and a microcontroller, characterised in that the signal generator (1) with a frequency of 433 MHz has two signal output ports, one port of which is connected to a directional coupler (2) and the second port is connected to a signal measurement module (3), and furthermore the directional coupler (2) is connected to a probe (5) and to the signal measurement module (3), wherein the connections of the elements (1, 2, 3, 5) are made by means of a coaxial cable (4), while the signal measurement module (3) is connected by means of a cable (8) to a microcontroller (6), wherein the sensor is powered by a power supply (7) connected by means of cables (8) to the signal generator (1), the signal measurement module (3) and to the microcontroller (6).

[Claim 2] The radio sensor according to claim 1, characterised in that the probe (5) consists of a base (5a) made of an electrically conductive material and a copper wire (5c) with a diameter of 0.5-1 mm located centrally in the base (5a), which is covered with Teflon insulation (5b).

[Claim 3] The radio sensor according to claim 2, characterised in that the probe (5) is detachably connected to the directional coupler (2).

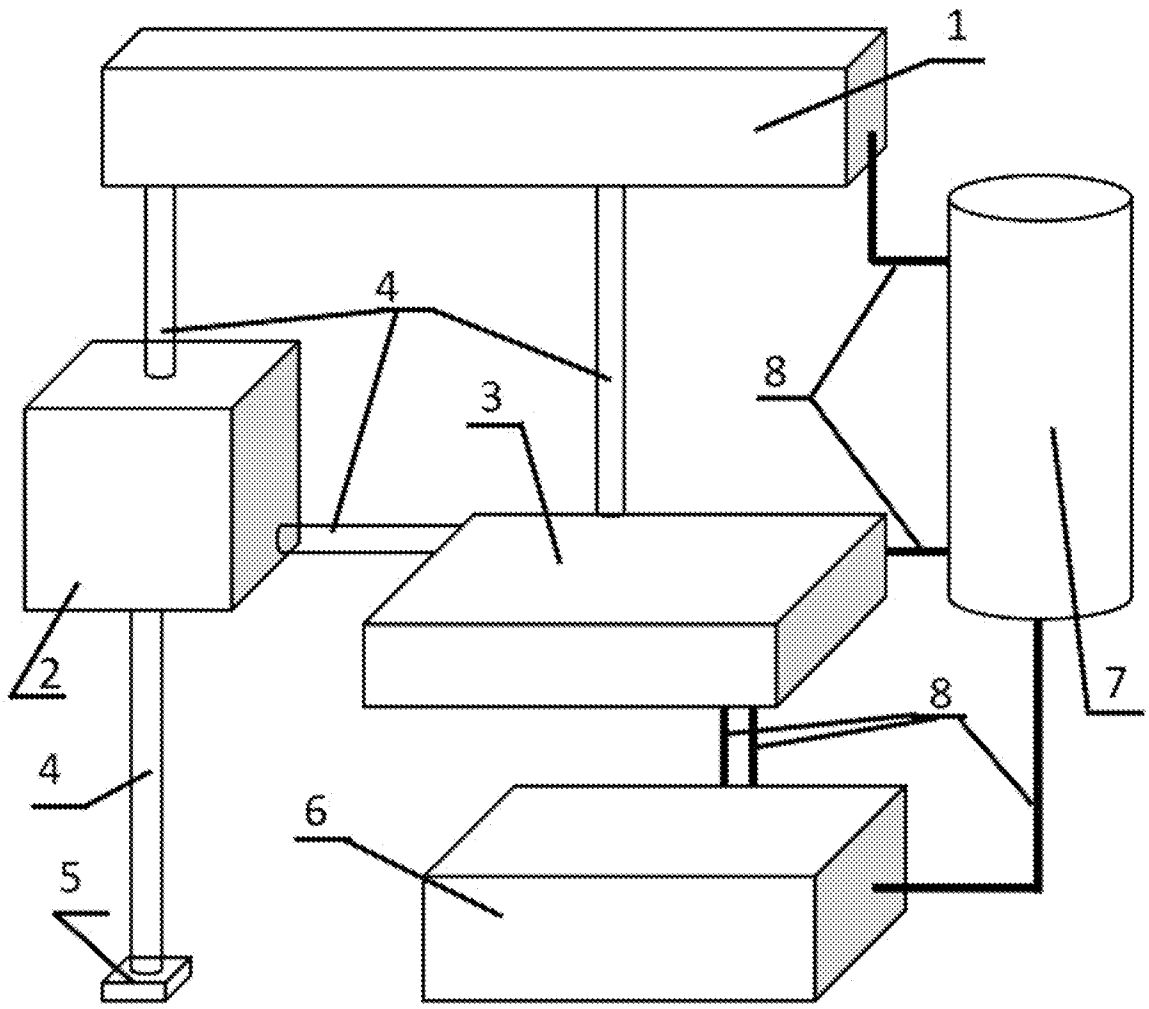
[Claim 4] A method of detecting material defects in 3D printer prints carried out using a sensor according to claims 1-3, characterised in that the probe (5) is placed at a certain distance from the surface of the tested material, then a signal with a frequency of 433 MHz is emitted by means of a signal generator (1), which is transmitted to the probe (5) via a first port using a directional coupler (2), and the signal is transmitted to a signal measurement module (3) via a second port, then the signal emitted from the probe (5), upon contact with the surface of the tested material, is reflected from it, wherein the phase of the generated wave and the reflected wave is analysed by a microcontroller (6), wherein the microcontroller (6) and the signal measurement module (3) and the signal

generator (1) are powered from a power supply supplied with a constant voltage of 5 V.

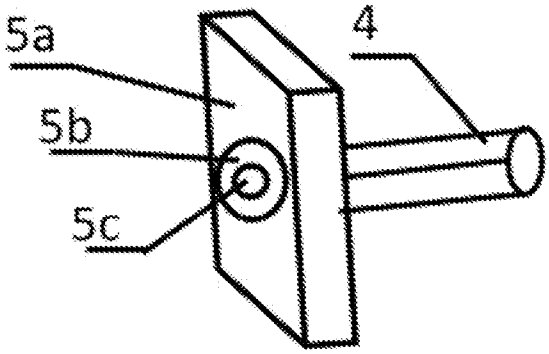
[Claim 5] The method according to claim 4, characterised in that the probe (5) is placed at a distance of no more than 0.1-1 mm from the surface of the tested material, preferably at a distance of 0.1 mm.

[Claim 6] The method according to claim 5, characterized in that the measurement is performed during 3D printing.

[Fig. 1]



[Fig.2]



INTERNATIONAL SEARCH REPORT

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PCT/PL2024/050038

A. CLASSIFICATION OF SUBJECT MATTER
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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)
G01N B29C

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2023/152090 A1 (MUKHERJEE SAPTARSHI [US] ET AL) 18 May 2023 (2023-05-18) paragraph [0011] - paragraph [0012]	1-6
Y	Wagner Norman ET AL: "Robust low cost open-ended coaxial probe for dielectric spectroscopy in laboratory and in-situ applications", In Proc. 6. CMMAt: Karlsruhe, GermanyVolume: 6 / 91-102, 1 October 2011 (2011-10-01), pages 1-11, XP093211989, Retrieved from the Internet: URL:https://www.uni-weimar.de/~skom8204/hydra/pdf/WagnerSokollSchimmer_CMM2011.pdf [retrieved on 2024-10-06] paragraph [0002] paragraph [0005] figures 1,2	1-6

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☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2023152090 A1	18-05-2023	NONE	