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Mechanical Structure Design of a Robot for Vibro-Acoustic with Scanning Testing

COMEAGĂ Daniel Constantin[a], UDREA Constantin[b], DONŢU Octavian[c] and NECULA Cristian[d]

[a,b,c,d] University POLITEHNICA of Bucharest, Splaiul Independentei 313 Str. , Bucharest 060042

[a]comeaga@hotmail.com, [b]dinuudrea@yahoo.fr, [c]octavdontu@yahoo.com, [d]cristianecula@yahoo.com

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Abstract. The paper is presenting a system derived for the automation of the acoustical and vibration measurements. The evaluation of noise emitted by an object by measuring the acoustic intensity according with the ISO 9614-3:2002 international standard requires displacement of the probe on spatial trajectories with constant speed and maintaining the spatial orientation of the probe. In a previous work a robot was design by the authors for performing this task, including a unit with 3 translations and an orientation unit with 2 rotations. The practical tests of the first system shown high difficulties in maintaining the constant speed due to the robot dimensions and inertia. Also the noise produced by the translational units during scanning was too high. The system is improved by adding 1 degree of freedom at the orientation unit, reduction of noise and new software version. The new mechanical structure is presented in this paper.

Introduction

The present tendency in engineering is the automation of the procedures and assurance of a high objectiveness degree in manufacturing and testing. This requirement is applying also in the products testing stage, which is time consuming. If at punctual measurements (measuring a parameter in a single point) the present automated testing systems assure a high degree of automation and allow to make high accuracy measurements with a minimum intervention from the human operator during testing, for the applications who require measurements in many points (modal analysis, making acoustic emission maps of the objects) the human factor is an important source of errors. The modern solution is to automate this process by using transducers without contact and positioning and orienting them with the help of the measurement robots [1], [2].

The main goal of the project whose result is presented herein was the achievement of a system – a certain type of robot, placed within an anechoic room, which will have to move in space an intensimetry probe, continuously oriented to the normal of the testing surface. This kind of robot can fulfill the measurement and/or testing conditions of the noise levels from different sources, in this way situating in space different measurement instruments, according to the stipulations of various standard procedures and methods. In accordance to the main objective of the project, the robot will have to fulfill also the conditions of the latest and most complex standard for the measurement of the acoustic intensity ISO 9614-3:2002 [3]. This standard settles an exact measurement method of the acoustic power through spatial scanning with an intensimetry probe for a scanning surface associated to the noise-generating source. According to this standard, against all the other acoustic standards, in which the measurement instrument is in repose in the measurement moment, in this case the intensimetry probe has to move continuously, with constant speed and on very precise trajectories. Those trajectories will cover through scanning all the surfaces or parts of the surfaces, who are limiting the volume surrounding an object whose noise level/acoustic power must be measured. The spatial robotized scanning covers in the same time all the requirements of some experimental researches, which have to optimize in a constructive way in order to reduce the noise emissions of certain products (domestic, production/manufacture, etc).

For satisfying the stipulations of the ISO 9614-3:2002 standard [3], the robot to be designed, manufactured and used within the anechoic room for displacement of an intensity proble must fulfill two technical conditions of great difficulty:

- the designing of a minimum 6 mobility degrees robot, who must generate scanning spatial trajectories (parallel, go and back, passing over) while it is moving with constant, programming speed, regardless the lateral surfaces types of the scanned volumes: prismatic, cylindrical or spherical. This is enforcing a very complex control program with movements and speeds interpolation, which in order to impose a constant speed on the trajectory, it must guarantee almost permanently continuous variable speeds on the coordinates axis;
- a robot whose own noise level during operation must be 20 dB smaller than the one of the testing source/product.

Mechanical structure of the robot

The first proposal of a robotized system was dedicated to the displacement of an acoustic intensity probe [4] and was kinematically composed by a positioning structure with 3 translations which is moving an orientation unit with 2 rotations and one translation (Figure 1 and Figure 2).

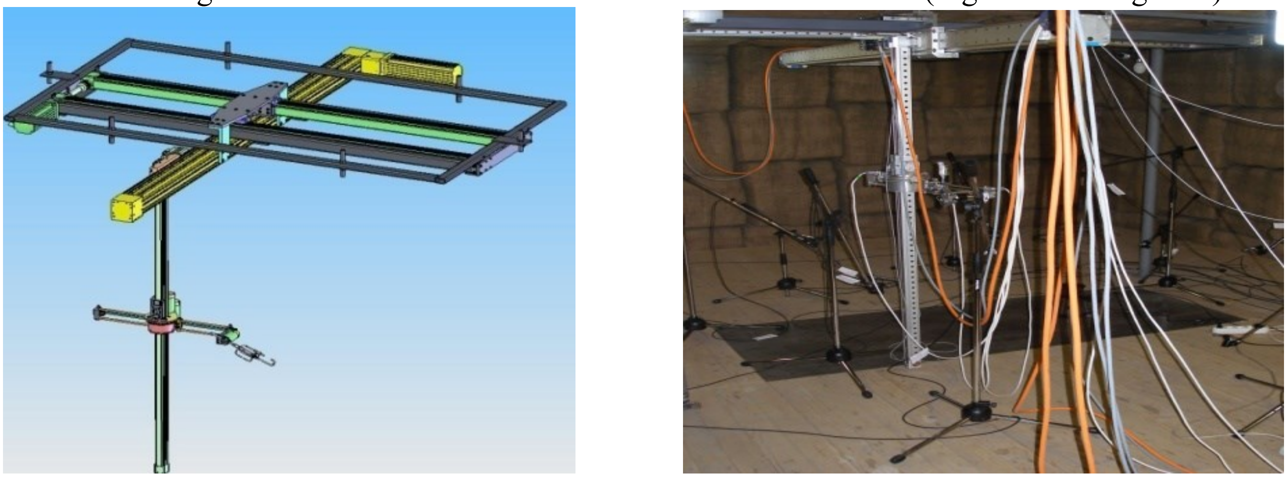

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Fig. 1 The initial structure of the robot for automatic measuring of the acoustic intensity:
(a) General view; (b) Translation subsystem

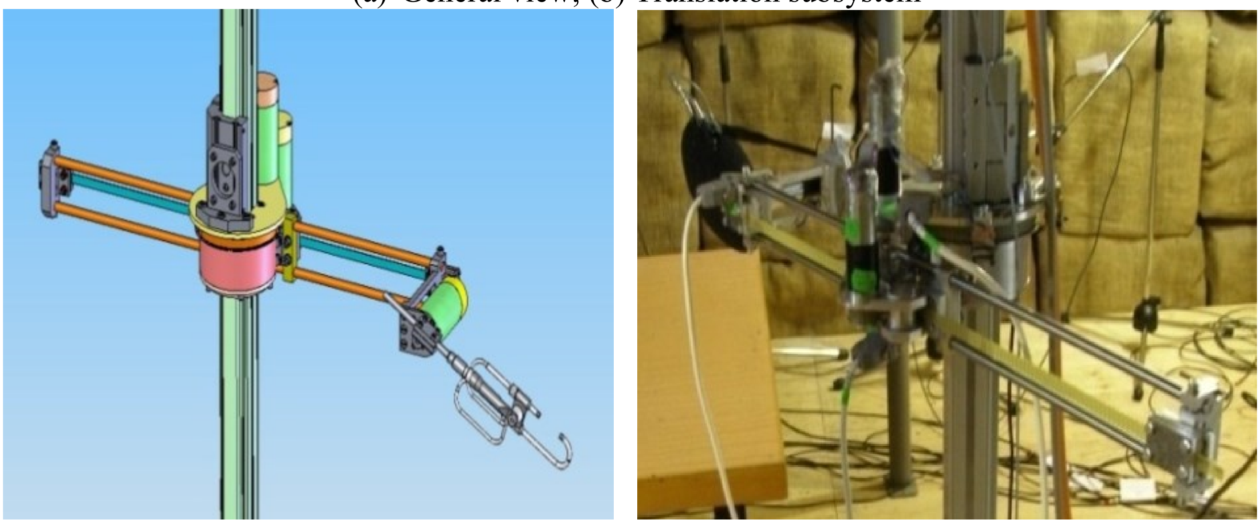

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Fig. 2 The initial structure of the robot for automatic measuring of the acoustic intensity:
(a) General view of the orientation assembly; (b) Orientation unit subsystem

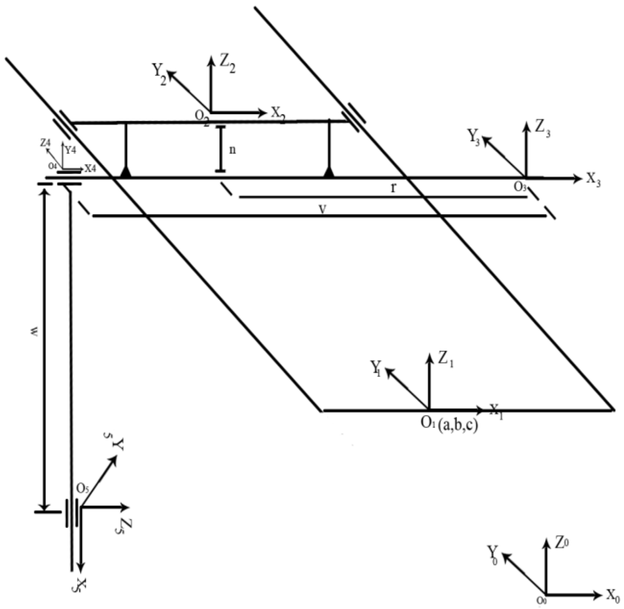
The robot was placed into a semi-anechoic room used also for acoustic power measurements as imposed by the ISO 3774/3745 standards. It was decided to modify the mechanical structure in order to improve the behaviour to vibrations and to introduce port-cables for guiding the signal cables, the cables for motor supply/control and the cable from the acoustic transducer. Also an improvement of the orientation subsystem was done.

The resultant structure is also composed by 2 assemblies:

- one positioning sub-system with 3 translations;
- one orientation sub-system with 3 rotations (there is also a translation but redundant to the ones from the first subsystem).

The positioning assembly with 3 translations is comprising 3 positioning sub-systems (Fig. 3):

- an assembly with 2 translation units DGE-40-1600-ZR-GF-GK-LB-RK-KG FESTO type; the 2 units shafts are connected with a transmission unit and are driven simultaneous by a single motor Festo MTR-AC-100-3S-GA;
- a positioning unit DGE-63-1600-ZR-GF- GK-LV-RK-KG FESTO type, driven by a Festo MTR-AC-100-3S-GA motor;
- a positioning unit DGE-25-1425-ZR-GF- GK-LV-RK-KG FESTO type, driven by a Festo MTR-AC-55-3S-AB motor with internal brake.



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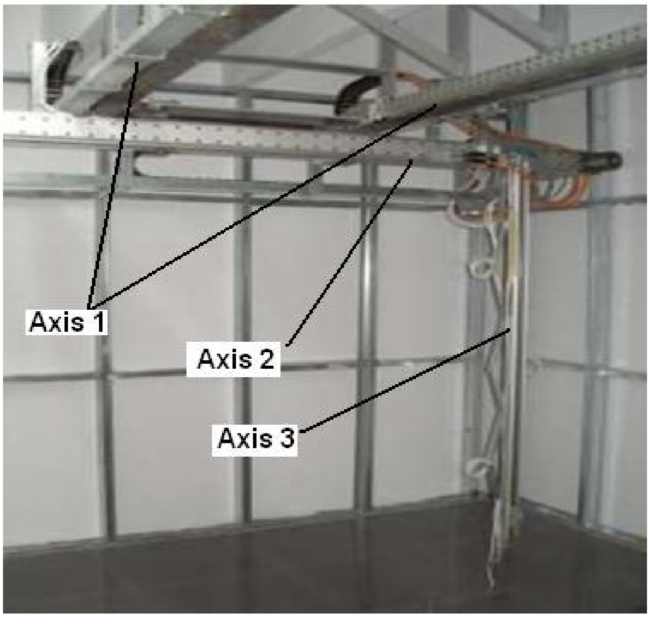


b)

Fig. 3 Positioning assembly with 3 translation: (a) Kinematic structure and assembling between units; (b) Practical design

For the DGE-40 double axis system type and for the DGE-63 axis type, a guiding system of the signal and supply energy cables was designed and made, to carry the cables for the motors and the cables from the limit transducers, then adapted to avoid the mechanical contact during displacement between the rigid elements in order to reduce the noise emitted during movement. For the vertical translation unit a pliable guiding system of the cable was conceived. The positioning system with three translations is allowing placing the transducer in a point in space.

Most of the applications require also its orientation on an established direction in space (usually identical or perpendicularly on the object surface in the measuring point).

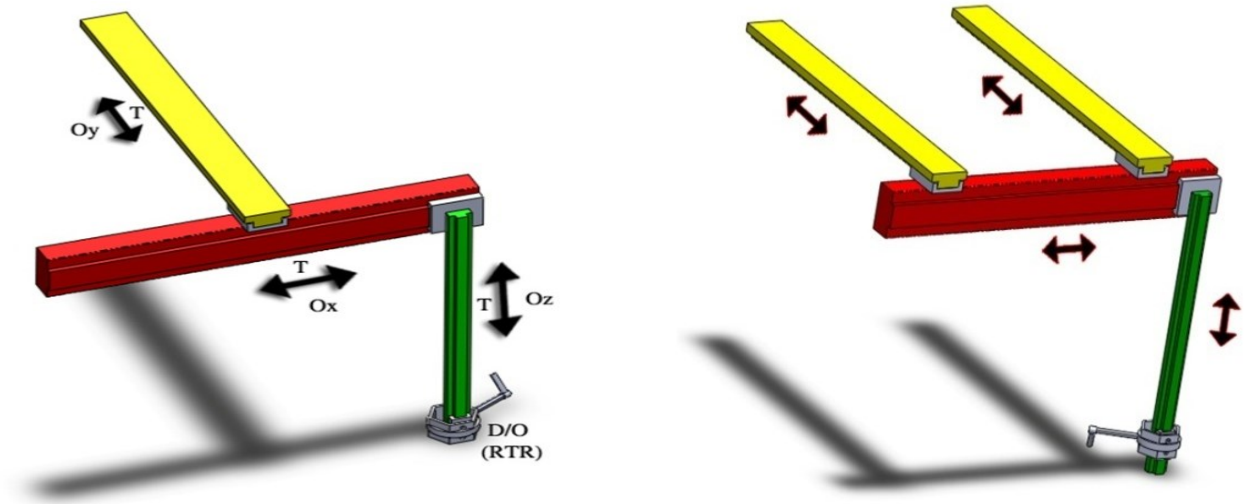
Kinematical speaking this is imposing the assurance of 3 rotations in space. In reality one of the rotations is leading only to the transducer rotation against its own symmetry axis, which is not useful at the usual transducers (laser vibrometer with a single fascicle or microphone/acoustic intensimetry probe). Therefore only 2 rotations for simple tasks are necessary: one in respect with the vertical translation axis and a single rotation in horizontal plane.

Due to the fact that the vertical translation is assured by the displacement of the vertical unit mobile part, which is carrying the orientation unit, it is not possible to position the unit above the object. A solution could be using a telescopic positioning system for the vertical direction. The studies accomplished for different possible structures did not offer enough stiffness. Therefore the option was introducing an arm in the structure of the orientation unit, which is allowing placing end part of the rotation unit and the transducer holder in plane over the object at a certain distance from the vertical axis. For more complex measuring tasks, an example being the measuring using an array of microphones for acoustic holography, a third orientation unit is necessary. This improvement was also done in this work.

The Oy-axis is the axis of the support of the whole system. Along the axis Oy, the Ox axis perform a translatory movement by means of a sliding guide located on the axis Oy. Along the Ox-axis is displaced the Oz-axis coupled to the carriage. The device for orientation of the transducer will slide along the axis Oz (Figure 4).

Improvements in the structure of the translation system

Few design posibilities were studied (Fig 4).



a) b)

Fig. 4 The proposed solutions for positioning system:

a) Representation of the subassembly positioning with one Oy translational axis;

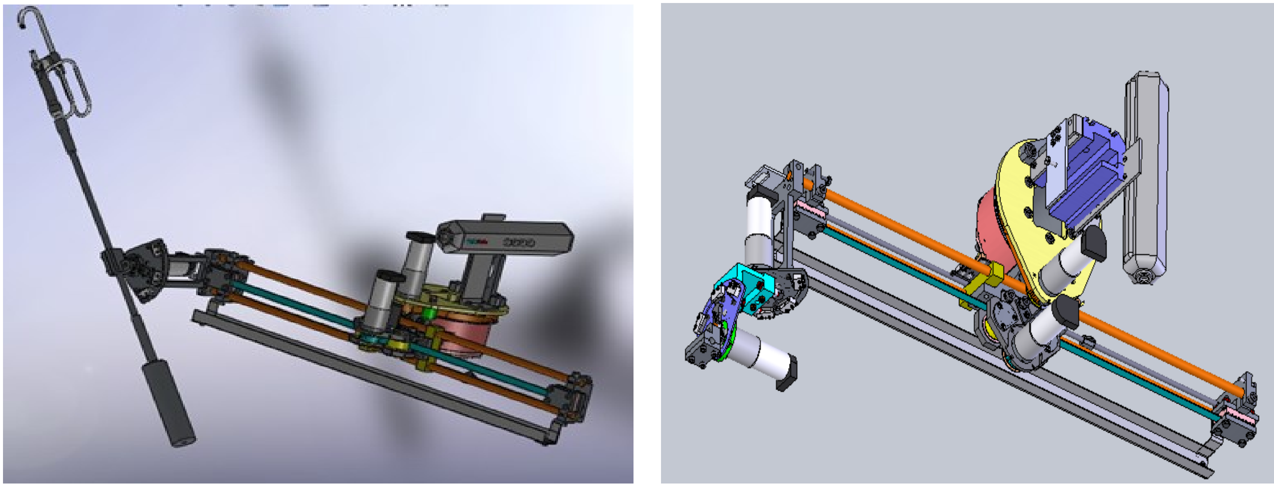
b) Representation of the subassembly positioning with two Oy translational axes

A single-axis version is very convenient in terms of assembly, however, alternative with two axes is very complicated from the point of view of installation as the two axes should be aligned very accurately. Not only must the guide axes be aligned in the same plane, but at the same time must also be parallel. On the other hand, the movement must be transmitted at a very rigid axle to the other, or one of the glides has a tendency to move before the other and will cause interruption of the movement. The transmission must be very rigid but to allow small miss alignment of axes. Such a structure with translational axis is very suitable provided that the guides are very quiet during movement, mainly if the structure is used for scanning. Metal roller guides are inherently slightly noisy. Another possibility is the use of rubber rolling part, but the loading capacity is significantly much lower. There can be used instead of metal beads, rubber beads. The most silent design construction would be the guides of sliding friction, which have the disadvantage of a higher friction (a controllability movement more difficult) but as the system is not required to operate at high speeds is not a problem if there is a guide that would limit accelerations during movement. This version is based on a guided sliding friction. Because positioning subassembly was designed to operate with relatively high speeds occurs problems regarding noise produced by the moving of the portcables components and the contacts between cables-portcables parts or portcables guidance-portcables parts. To reduce noise during operation of the robot, the energy chains for power and transducers cables from the positioning axes were modified and also the cables from the acoustical transducer.

The aim was to absorb noise by attaching silicone dampers between the portcables system parts and support them using brackets lined with absorbent material.

Improvements in the orientation systems

The idea of extending the work done in the first phase of the project was to improve the robot automation, vibration and acoustic emission, including improving the orientation capabilities, besides adding at the existing three degrees of freedom (DOF), one more DOF.



a) b)

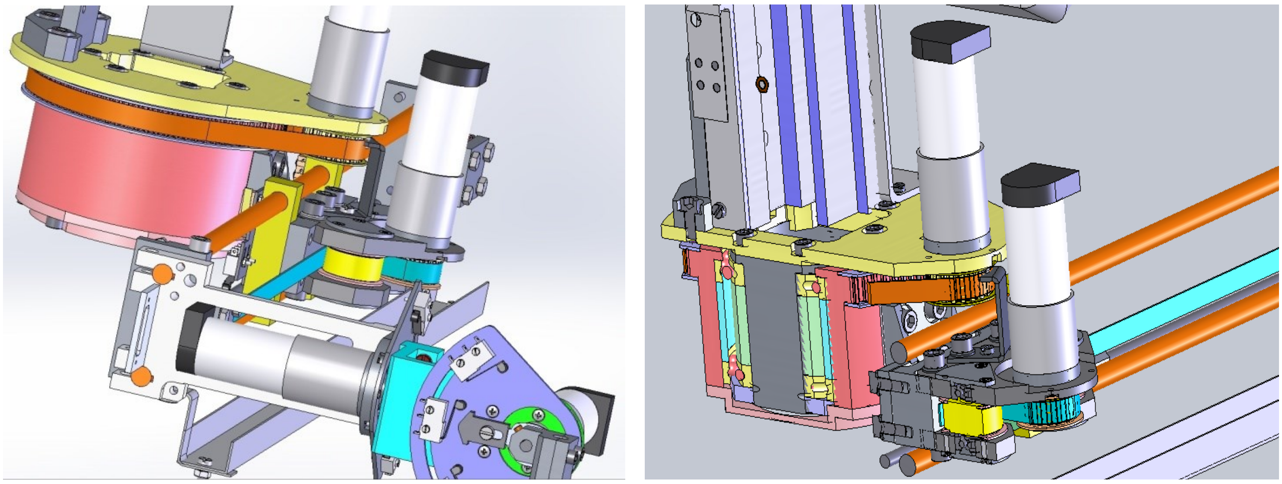
Fig. 5) The proposed solutions for orientation system:
a) The initial orientation subassembly; b) The orientation system improved to 4 DOF

The orientation subsystem should provide minimum 2 degrees of rotation, to allow orienting the measuring direction of the intensity probe in any imposed direction in space. Due to the vertical rigid axis is imposible to measure over an object. In the initial design for solving this issue was added a translation axes in a solution with a rotation around the vertical axis of translation subsystem combined with the supplementary translation axis and end rotative movement. The main disadvantage of this design is the large bending load acting on the guidance of the vertical rotation. This guidance include 2 bearings placed at distance, on the vertical axis carriage (Figure 6). The driving of the rotation around the vertical axis is done using a DC motor and a reduction with toothed belt. Two microswitches were used for limiting the movement. The movement range was limited to 3200÷ 3400. To extend the range are actually used optical switches and reflective marks placed on the belt. The vertical orientation mechanism is computed so as the belt length is much longer then the circumferential length of the toothed wheel placed on the vertical axis, allowing placement of the optical marks so as the vertical rotation is limited to 3650. The mechanical switch is used only as home signal. The supplementary translation plane is moved relative to the place containing the axis of rotation.

The supplementary axis is drived with an electric motor. Due to the fact this axis is very close to the measuring instrument the noise emitted is critical. So it was chosen a friction based guidance solution for this axis. The driving use a toothed belt solution from two reasons:

- the noise is much lower than for a screw based driving;
- the robot should provide learning posibilities for the orientation subsystem, this means to measure and store the position resulting from manualy moving the transducer.

The tensioning mechanism for the toothed belt is using two additional roller by which one is mobile during tensioning. The guiding for cables is placed under the translation unit.



a) b)

Fig. 6 Design solution for orientation subansembly:
a) CAD model of orientation subanssembly; b) Section view of orientation subanssembly

At the end of the supplementary translation assembly it was placed the end rotation, completed actually with another rotation. For intensity measurement the added rotation is not useful because it is providing only a rotation of the microphones around their axis but is very useful when using an intensity measurement with 3 probes ortogonally oriented or using a microphone array for acoustic holography. For the end rotations are also used DC motors with internal gears. For limiting the rotations mechanical swithes and a cam placed on the mobile element are used. Mechanical switches are limiting the movement in both direction with the possibility to move their position for control of the useful displacement range. A home switch is also placed on the vertical rotation unit unit and a cam on the mobile translating part.

Summary

The main goal of the project whose result is presented herein was the achievement of a system – a certain type of robot, placed within an anechoic room, which will have to move in space an intensimetry probe, continuously oriented to the normal of the testing surface. In accordance to the main objective of the project, the robot will have to fulfill also the conditions of the latest and most complex standard for the measurement of the acoustic intensity ISO 9614-3:2002. In a previous work a robot was design by the authors for performing this task, including a unit with 3 translations and an orientation unit with 2 rotations. The practical tests of the first system shown high difficulties in maintaining the constant speed due to the robot dimensions and inertia. Also the noise produced by the translational units during scanning was too high. The paper is presenting an improved version of a scanning robot designed initially for acoustic intensity measurements but with new possibilities for performing acoustic holography. The improved design has 7 DOF, one is redundant but imposed by construction constrains for achieving full kynematical capabilities. The structure was designed and manufactured being used in a laboratory for acoustical testing.

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