Application of Vacuum Technology in Precision Engineering Design

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Abstract. *The requirement of closer dimensional tolerances in manufacturing of high technology products is a standard that seeks a balance between their characteristics and cost, this being one of the pillars of precision engineering. Therefore, the continuous improvement of manufacturing techniques and measurement as well as the prioritization of the technologies supported by each process, makes the precision engineering to develop mechanical designs more elaborate in order to meet the manufacturing of these products. Thus, the requirements for controlled conditions of temperature, humidity and vibration are not enough anymore, being necessary to control the surrounding atmosphere through the vacuum technology. As examples of the problem, contaminates the atmosphere uncontrolled manufacturing processes through oxidation of the surface in contact with the environment besides forming molecular layers of deposits, which in certain cases, invalidate the entire process, as in the manufacture of semiconductor devices, as well as the difficulty of increasing accuracy in metrology without contact. Flexibility, speed and larger effective measurement area, and did not damage the surface, characteristics of the fasteners are applied in a vacuum tables on machine tools. This work deals with the redemption of the literature on vacuum technology covering the basics and their state of the art applications in precision engineering followed by a design and development of applied vacuum tables on machine tools. In design and development of vacuum tables, is described and applied a method, which consists of vacuum sizing tables capable of securing parts through the machining machine tools.*

***Keywords**: Vacuum technology and applications, Vacuum tables, Machine Tools*

1. INTRODUCTION

In recent decades, technological advances have grown to meet the demand for increasingly sophisticated products in order to meet consumer demands. Resources, scale integration, miniaturization, and design costs, are some of the features that guide the improvement of these products. In this sense, the design and manufacturing processes has been adequate to achieve closer dimensional tolerances. According to Venkatesh and Izman (2007), not only just the best use of machine tools to manufacture products with the desired accuracy, but the use of advanced high-precision machines are compatible with each process.

Precision engineering is a discipline concerned with the continuous improvement of processing techniques for improving products (Smith and Chetwynd, 1992). According to Venkatesh and Izman (2007), the development of machining techniques enabled the fabrication of high performance, adding value to products, as examples of precision components for computers, electronics and nuclear energy. However, these techniques require tolerances from micrometer to nanometer depends on the applied machining process. In addition, the measuring devices should have performance capable of measuring the tolerances required for each manufacturing process. However, these advances have been difficult by obstacles inherent to manufacturing process as well as the level of atmosphere control, which are increasingly aggravating when high accuracy is required. For Smith and Chetwynd (1992), greater care is needed with mechanical designs, which may include concepts of non-trivial normal practice of engineering. Depending on the application requirements under controlled temperature, humidity and vibration are not enough, then it is necessary, control of this atmosphere. As examples of the problem, contaminates the atmosphere uncontrolled manufacturing processes through oxidation of the surface in contact with the environment besides forming molecular layers of deposits. The solid particles in suspension deflect the light beams, and when applied to non-contact metrology, complicates the issue of increasing accuracy. Miniaturized devices in nanometer scale and micrometer, are completely contaminated by molecules of the medium. Therefore, control of the atmosphere from the vacuum technology is one of the fundamental disciplines in certain applications in precision engineering.

The vacuum technology initially treated by the ancients as philosophical curiosity today is a technology essential to the modern world (Chambers, Fitch and Halliday, 1998). Since it is the control of the atmosphere in order to extract molecules of the medium, this technology brings improvements to be achieved and processes that are affected by the standard atmosphere (Degasperi, 2002). Therefore, applications that have problems controlling suspended solids, oxidation, formation of molecular layers on a surface, molecular shocks, removal of active gases and fixing parts and tools are some of the problems benefit from this technology. Coupled with precision engineering, vacuum technology has allowed the breaking of barriers that limited the use of demanding applications besides improvements of existing ones, promoting technological advancement. Manufacture and manipulation of micro and nanomechanical machines, electronic chips, surface cleaning by vacuum drying and fixing parts are some of the numerous applications of vacuum technology in precision engineering.

This paper describes the principles of vacuum technology and the need of this technology in applications of precision engineering, followed by a methodology of design and development of vacuum tables to fix the parts to be machined on machine tools. It should be noted, the lack of technical and scientific articles regarding the design parameters, design methodology, specifications and mechanical properties of materials in vacuum tables, the latter being the motivator for the development of this research project.

2. FUNDAMENTALS AND OBJECTIVES OF VACUUM TECHNOLOGY

In ancient times (322 -384 BC), Aristoteles defined the vacuum as "empty" or a kind of "private space of the body" as a logical impossibility in nature, since philosophers and ancient Greeks believed in the matter as a solid substance and unaltered (Saunders and Brown, 2002). This understanding of the substance and philosophy among others raised by Aristoteles departed from the concept of vacuum for about 1900 years and were only dropped from the first experiments of Torricelli that paved the way for the development of vacuum technology. (Ryans and Roper, 1986). Figure (1) illustrates a generic system consisting of vacuum chamber, vacuum pump and pumping line. The vacuum pump is designed to create a pressure difference inside the pipe and vacuum chamber in relation to the collector of the pump suction, causing an imbalance of pressure in the system (Moutinho, Silva and Cunha, 1980). This pressure differential promotes a flow of gas contained in the system, the feeling of evacuating the amount of gas proportional to the difference created by the pump. Consequently, the greater the pressure difference, the smaller the amount of gas existing inside the vacuum system, as well as pressure.

The role of the pumping line in vacuum systems is not only connecting the vacuum pump chamber, but also create an entire circuit linking devices inherent in the system (O'Hanlon, 2003). In some cases, pumping line can be flexible to meet the mobility of the application involved, or it may have a rigid access windows, pressure taps and valves specific as in the case of more complex vacuum systems.

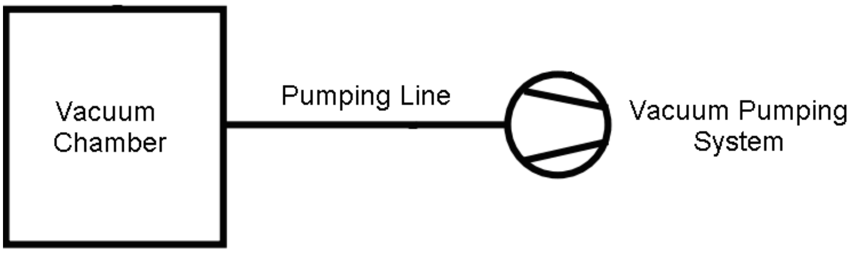

Figure 1. Generic configuration of vacuum systems

The camera is the most interesting element in the vacuum system since it is here that the experiments and applications are made, since it provides a closed environment with a controlled atmosphere. It is the element that closes the circuit of the vacuum system, and the other devices involved must produce and ensure the required low pressure in the chamber. The vacuum chamber must withstand the stresses caused by the atmosphere when subjected to external pressure difference. According Degasperi (2002), the use of vacuum can create pressure differences in the order of 10^5 Nm^{-2}, can be used not only to create a controlled atmosphere, but also for setting and forming heated plastic objects, plus a series other applications that benefit from the force generated by vacuum.

The DIN 1343 stipulates that the standard atmospheric pressure relative to sea level is 101.325 kPa in the international system or 1013.25 mbar customarily used by manufacturers. For the Ryans and Roper (1986) any system that obtains a pressure below standard atmospheric pressure is defined as the vacuum. Therefore, the difference in pressure of the system is calculated by the difference between the atmospheric and vacuum pressures obtained in the chamber, taking into account that the biggest difference of pressure which can theoretically be obtained is 101.325 kPa, since the absolute vacuum is a theoretical aspect. Adam et al. (1998) explain that the absolute vacuum is impossible to get it due to leaks in the system, limits the pump suction and interaction of the walls of the chamber with the gas molecules. For any volume and pressure typically used in laboratories, there is a large number of molecules (O'Hanlon, 2003). When subjected to standard atmospheric pressure at a temperature of 22°C, a cubic meter of gas has 2.48×10^{25} ideal molecules, and even in conditions of low pressure in the order of 10^{-7} Pa, there are still 2.5×10^{13} molecules. This quantifies the difficulty of the vacuum systems evacuate a large number of molecules, and even the impossibility of removing them all, given the leaks and imperfections of the devices used and the kinetic behavior of molecules. Consequently, each range of molecular behavior change will be associated with a specific group of applications become more complex each time the requirement of controlling the amount of molecules in the atmosphere is greater.

Hoffman, Singh and Thomas (1994) emphasize the goals of vacuum technology applied within four physical classifications as follows:

Low-pressure situation: Within this classification, the vacuum technology aims to create a pressure difference between the internal and external to the vacuum chamber. This difference in pressure applied to a contact area generates a net force is used to warp, split, suspend, sustain, brake, cleaning, transport, lay and collect. In this classification, the vacuum technology is only concerned about the pressure difference is able to withstand loads and is not relevant to disposition of the molecules as well as the mode of gas flow. The contact area and friction coefficient between the materials are objects of study of great relevance.

Physical situation of low molecular density: Within this classification, the vacuum technology aims to remove particles and molecules in order to reduce contamination in the evacuation process of the active gases present in the environment. The evacuation removes the chemically active gases inside the vacuum chamber, prevents unwanted chemical reactions like oxidation, and allow the formation of inert atmospheres to melt, treat metals and packaging products. It also removes dissolved gases in materials such assets from the low and high drying temperatures and vapor extraction of liquid and solid materials.

Physical situation of large mean free paths: Within this classification, the vacuum technology aims to minimize the effect of the number of collisions between molecules ensured an environment free from most disturbances. This classification is used in most demanding applications and also those directed to the areas of research. The study of the dynamics of molecules and the state of gas flow are of great importance in this classification. The smaller number of molecular collisions allows a smaller deviation of electron beams and light. Used in cathode ray tubes, X-ray oscilloscopes, particle accelerators, mass spectrometers and optics, welding machines, electron microscopy, evaporators for thin films, storage rings and particle separators isotopes.

Physical situation of long lead times for the formation of a monolayer: Within this classification, the vacuum technology prioritizes the effects of the formation of a molecular layer on the surface of a material. The formation of this layer is based on the number of shocks in molecular wall material, which however may have an estimated time within known parameters when subjected to very low pressures. The main goal is to get clean, with few adsorbed gases, or retained by the surface material. Applied to surfaces to the study and application of films, electron emission, variation of friction coefficient, surface physics studies, nanotechnology, doping materials and also in aerospace studies.

The objectives of vacuum technology comprise a broad range of applications ranging from the simplest to the most complex, considering that the difference between each application is determined by the level of vacuum required. Consequently, each vacuum level requires a different kind of approach to the vacuum system used in relation to pumps, pipes, materials and devices that build up the system. Thus, bands of vacuum pressures were delimited in order to organize the scope of cover one. The vacuum technology was divided into bands of arbitrary pressures that determine the level of approach to the design of vacuum system and the type of application involved (Chambers, Fitch and Halliday, 1998). According to Adam et al. (1998) each area of concentration deals with these tracks in a particular way, that is, for chemists, the vacuum can is understood only in the ranges from 100 to 1 mbar. For engineers, this band is far more generic and comprehensive, encompassing the entire spectrum of about sixteen powers of ten. The Table (1) presents the characteristics of each level of vacuum pressure as Ryans and Roper (1986).

Table 1 – Vacuum pressure level

Level vacuum pressure	Nomenclature
Atmosphere – 100 Pa (1 mbar)	Low vacuum
100 Pa – 0,1 Pa (10^{-3} mbar)	Medium vacuum
0,1 Pa – 10^{-5} Pa (10^{-7} mbar)	High vacuum (HV)
Abaixo de 10^{-5} Pa (10^{-7} mbar)	Ultra-high vacuum (UHV)

The higher the level of vacuum pressure required for an application, more detailed and complex becomes the vacuum system involved, besides the higher cost of implementation and maintenance (O'Hanlon, 2003). Adam et al. (1998) also claim that in every situation of vacuum range, the gas has a different kinetic behavior. Given this fact, it is necessary that the designer knows the correct classification of vacuum pressure required for a particular application so as not to oversize the system.

3. VACUUM TECHLONOGY APPLIED IN ENGINEERING PRECISION

The vacuum technology is used in many precision engineering applications, among them the metal forming with better surface finish, prototyping resin and metal, non-contact metrology, manufacturing of devices in micro and nanoscales, atomic microscopy and fixation devices. Following some of these applications in metrology, nanomanufacturing and fixation devices are presented.

3.1. Metrology

Advances in micro and nanotechnology areas of miniaturization of electronic devices and mechanical metrology systems require high precision and accuracy as well as more sophisticated calibrators for these systems. The low number of molecules contained in the high vacuum ensures less disruption to the laser beam as a way to stabilize the wavelength, and second Sawabe et al. (2003), the index of refraction is eliminated. From this, Sawabe et al. (2003) developed an interferometer comparator for calibrating of linear encoders used in sophisticated positioning systems, such as those used in measurement in the semiconductor industry and metallurgy, reaching a measurement uncertainty of 40 nm. Figure (2) presents an overview of the comparator, where the displacement of the table is measured by a laser interferometer contained in a vacuum chamber at high vacuum of 8^{-5} mbar.

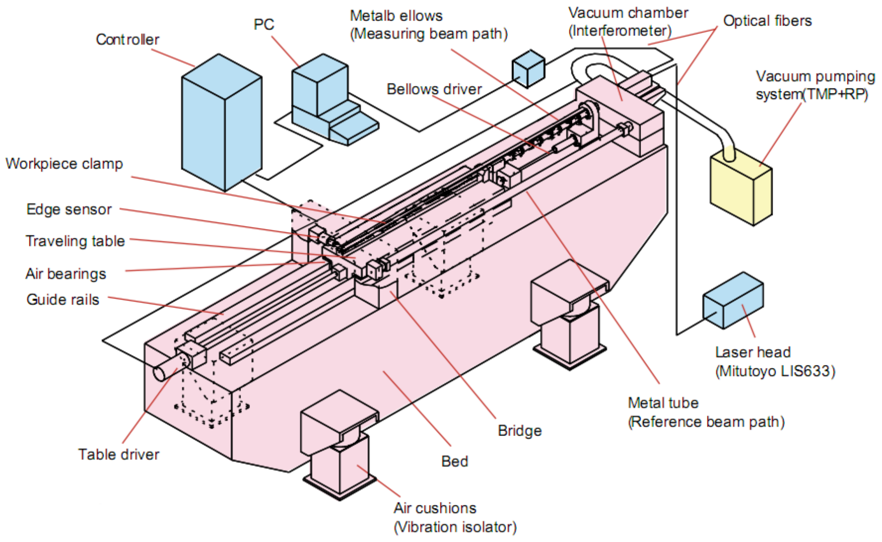

Figure 2. Interferometer
Sawabe et. al, 2003, p. 321

Yang et al. (2006) showed an experimental mass measurement using a sensor nanoelectromechanical (NEMS) with sensitivity zeptogram scale (10^{-21} g) that operates within a system of ultra-high vacuum cryogenic 10^{-10} mbar. The operation of NEMS is given basically by the amount of gas molecules adsorbed on it, from a nozzle adequately controlled with a shield that blocks the flow of gas pulsed, as Fig. (3).

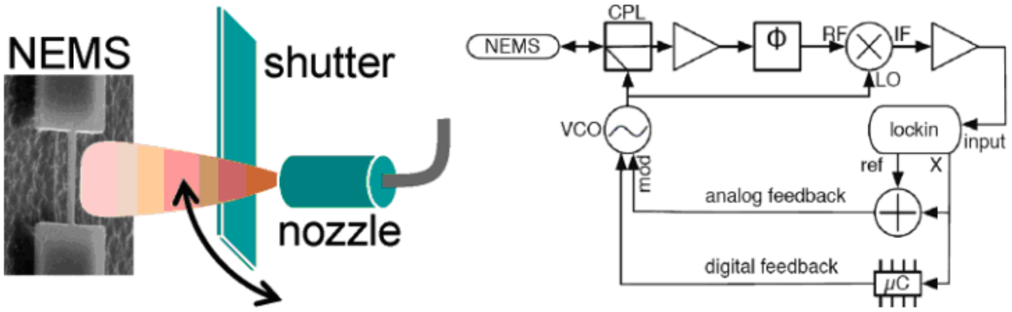

Figure 3. NEMS Meter
Yang et. al, 2006, p. 584

3.2. Nanomanufacturing

The area of nanofabrication is also assisted by vacuum technology that provides a controlled environment for Electron Beam Lithograph (EBL), which according Olmos (2008) is the technique of nanofabrication structures are used. Basically consists of an electron beam that scans a surface multilayer sensitive to design a structure that is subsequently removed to form nanostructural layers. According to Olmos (2008), this process has high manufacturing resolution due to the electron beam has a small diameter of attack on the surface to be drawned, reaching a diameter of 1 nm instead of 500 nm of lithography process for beam of light without using a controlled atmosphere.

3.3. Fixation

Vacuum tables are often used in machine tools, numerically controlled (CNC) machining centers and coordinate measuring machines. A vacuum table is capable to ensure the fixation of parts during the machining process without the need for the use of traditional fasteners, and promote the advantages of reduced assembly time, greater effective area of measurement with or without contact and greater accuracy of fixation (Paiva, Silva and Lima Jr, 2010a).

Vacuum table consists, basically, of a vacuum chamber that has holes in its upper part as in Fig. (4), to hold the workpieces by evacuation of the air existing in contact area between the table and the workpiece. This is similarly to a sucker, which creates a pressure difference that push the object against the pod. Manufacturers use a very small thickness film on the top of the table to improve the insulation of the vacuum pressure created by the holes and the surface of the workpiece, or in other cases are used gaskets. Other important features of the vacuum table are: small deformations due to vacuum pressure and external loads and low weight (Paiva, Silva and Lima Jr, 2010a). The next section presents a methodology for design and development of tables of vacuum applied to machine tools.

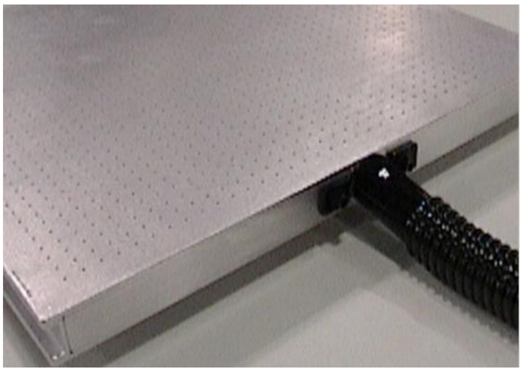

Figura 4. Vacuum table
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4. DESIGN AND DEVELOPMENT OF VACUUM TABLES

This section presents a methodology for design and development of vacuum tables to fix workpieces in milling machine in order to replacing the traditional tables that use staples and screws. The methodology is divided into two phases of design, where the first determines the vacuum clamping forces necessary to fix parts subject to different forces of machining. The second phase follows the design of tables for each vacuum clamping force, along with different geometries of the vacuum table, in order to assess the magnitude of effort and select the most appropriate table. In both phase were considered steel and aluminum as table materials.

4.1. Determination of vacuum attachment force (Phase 1)

To determine the clamping force in a vacuum table applied to milling machine tool, it is necessary to know the nature of the forces arising during machining. Ferraresi (1977) argues that these forces generated depend on technological considerations and physical characteristics of chip formation, and these considerations are highlighted by Brooks et al. (2006) as cutting speed, feed rate, depth of cut, tool material, coating material, tool geometry, cutting fluid, tool wear, thermal effects, friction and tension generated. In the present research work, actual magnitudes of forces obtained experimentally by Ribeiro, Abrão and Sales (2006) through a piezoelectric dynamometer installed in table setting in order to record the magnitude of machining forces in three axes, as shown in Fig. (4), where the passive force (F_p) is responsible for axial movement, and resulting from supporting forces (F_{ap}) and stroke (F_f) are responsible for lateral movement of the piece on the table setting.

Based on Figure (5), it was found that the axial force can be countered by a force of the same module and opposite, and that the resulting transverse force can be nullified by the force of friction existing in the contact surface of the vacuum table and part to be machined. The friction force depends on the normal force that is in the same direction of axial force (Paiva, Silva and Lima Jr, 2010b). Therefore, the friction force is given by:

$$F_{at} = \mu . N \tag{1}$$

Where:

F_{at} - Frictional force, which in this case is equal to the lateral force (N)
μ - Coefficient of friction between the pair of materials in contact
N - Normal force (N)

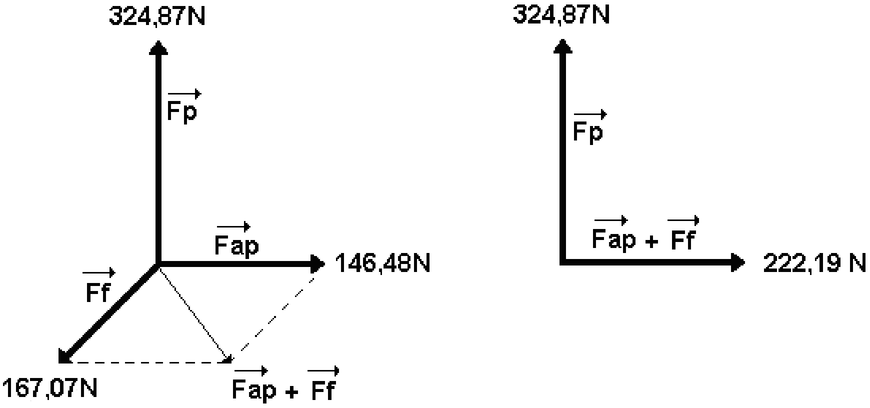

Figure 5. Machining forces

To calculate the normal force (N), was first admitted to the table and be part of steel, and according to Collins (2006) the typical value of the coefficient of static friction between the pair of steel-hard materials on steel is hard 0.45, resulting in a normal force of 493.76 N. The normal force (N) and passive (F_p) only reflect the reality of machining forces, since the weight force of the piece was discarded. It is worth noting that the fact of not considering the weight of the part requires the vacuum clamping force greater, contributing to a greater guarantee of fixing the piece. Therefore, the vacuum clamping force required must be at least equal to the sum of passive and normal forces totaling 818.63 N, and in opposite direction. But allowing a safety factor of 1.5, by supposing vacuum leaks in the system and poor seal between the workpiece and the table as well as fluctuations in the machining forces, the vacuum clamping force must be corrected magnitude of 1227.95 N (Paiva, Silva and Lima Jr, 2010b).

To determine the contact area it was applied to the equation that relating pressure, force and area, by considering the vacuum clamping force corrected of 1227.95 N. It was adopted a necessary vacuum of 100 kPa (1000 mbar) or absolute pressure of 13.25 mbar as vacuum pumps in this pressure range present flow stability (Paiva, Silva and Lima Jr, 2010b). Therefore, applying the equation, it was obtained a vacuum contact area of 0.0122 m^2 (110 x 110 mm). In this case, the pressure difference created by the vacuum system and applied in the contact area generates a vacuum force, since the atmospheric pressure will act on the part, pushing it against the vacuum table. The contact area of vacuum is defined by a rectangular slot of 2mm depth on the table surface, as shown in Fig. (6). This creates a small vacuum chamber between the table and the part that is fixed. The slot is bounded by a gaskets perimeter which works as sealing device similar to a sucker, according Fig. (6), (Paiva, Silva and Lima Jr, 2010a).

In this study, it was considered that the part to be fixed must have lateral dimensions sufficient to exceed the area bounded by the gasket, which comprises at least 130 x 130 mm. Also, the part must have high flatness, the absence of through holes. The gaskets chosen had square section of 3.175 mm (1/8") (Paiva, Silva and Lima Jr, 2010b).

To check the influence of table materials in the fixing force and in the lateral dimensions of the vacuum table, aluminum was admitted by considering the same machining forces and part material. To calculate the normal force (N), Collins (2006) defines as a typical value of 0.61 coefficient of static friction between the pair of steel-hard materials on aluminum, gaining normal force (N) of 364.25 N and the vacuum clamping force of 689.12 N. But admitting the safety factor 1.5, the vacuum clamping force must have a corrected magnitude of 1033.68 N. Applying the equation relating pressure, force and area, for a vacuum pressure of 100 kPa and vacuum clamping force corrected of 1033.68 N, was obtained from a vacuum contact area of 0.01034 m^2 (100 x 100 mm).

Based on calculations made previously, it can noted that the dimensions of the vacuum table upper surface vary with the type of material of table and the part to be fixed. Therefore, the coefficient of friction has a direct impact on the magnitude of vacuum clamping force required and consequently the dimensions of the table. Observe that these quantities decrease with the increasing of the coefficient of friction between the materials of the table and part, according to Tab. (2) (Paiva, Silva and Lima Jr, 2010b).

The next subsection discusses the design and development of the tables of vacuum to the second phase of the methodology through simulation, showing the magnitude of the efforts and relationship of stiffness/weight in different geometries.

Table 2 – Vacuum tables dimensions

Vacuum table material	Clamping force required	Clamping force corrected	Vacuum contact area (slot)	Total dimension upper surface table
Aço $\mu = 0,45$	818,63 N	1227,95 N	110 x 110 mm	150 x 150 mm
Alu $\mu = 0,61$	689,12 N	1033,68 N	100 x 100 mm	140 x 140 mm

4.2. Development and design of vacuum tables (Phase 2)

From the results shown in Tab. (2) in which are presented two solutions for the dimensions of the table upper surface. In this phase, it will be analyzed the efforts, displacement and the ratio of stiffness/weight for different configurations of the table core. The results of the efforts were obtained through computer simulation package NX 7.0, along with the tool of finite element analysis, NASTRAN. In this work, the NX 7.0 was used for modeling and analysis, since an analytical solution would be very difficult to be obtained due to the geometric complexity of the table.

The vacuum table dimensions considered in this analysis are: total height of 15mm, upper surface with 5 mm thickness, sidewall height of 10 mm and 5 mm thickness. To investigate the effects of geometry of the vacuum table core, on the displacements and stresses, three types of geometries for the table core were considered: hollow, square and hexagonal which are shown in Fig. (6) (Paiva, Silva and Lima Jr, 2010b).

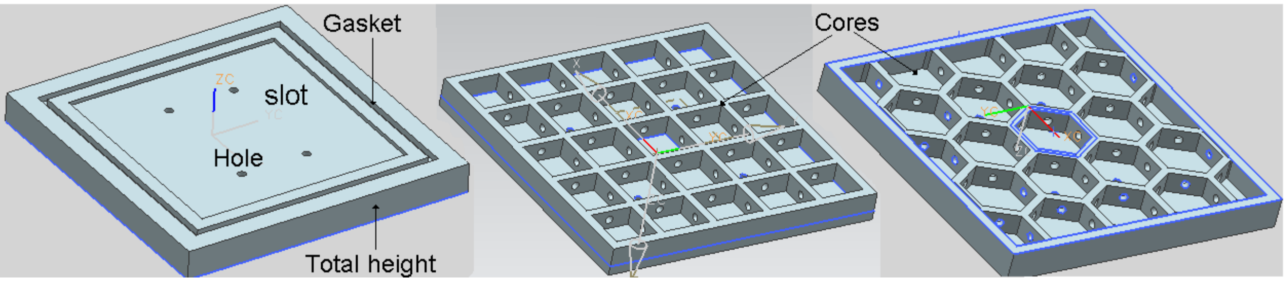

Figure 6. Vacuum tables configuration

For the vacuum table of 150x150mm was considered that core element square or hexagon has an outer perimeter of 120 mm with a thickness of 2 mm. All elements have a hole on each side with a diameter of 4 mm in order to promote the homogenization of the vacuum through better distribution of air flow. For the table of 140 x 140 mm the perimeter was admitted to be 109.09 mm. Next, the finite element method (FEM) with 3D geometry tetrahedron defined by 10 nodes in an isotropic solid material was applied. The quantity of elements and their dimensions are set automatically by NX 7.0 as mesh optimization. The material chosen was steel AISI 1005 (S_y = 226 MPa) for table 150 x 150 mm, and the boundary conditions of simulation applied in NX 7.0, the underside of the table was submitted to crimp any degree of freedom, and the remaining twenty faces (lateral and geometry of the top) were subjected to a pressure difference of 100 kPa distributed without any conditions crimp. For the table of 140 x 140 mm was used aluminum 2014 (S_y = 333,762 MPa). The Table (3) presents the final results of simulation calculated by NASTRAN that the maximum displacement and Von-Mises stress that was the criterion that was adopted in all analyses (Paiva, Silva and Lima Jr, 2010b).

Table 3 – Results of development and design of vacuum tables

Material / Density (kg/mm^3)	Core	Maximum displacement (mm)	Maximum stress (MPa) Von-Mises	Safety factor
AISI 1005	Vazado	$9,209 \times 10^{-2}$	67,240	3,361
	Quadrado	$2,160 \times 10^{-4}$	2,499	90,436
$7,872 \times 10^{-6}$	Hexagonal	$3,292 \times 10^{-4}$	3,239	69,774
Alu. 2014	Vazado	$1,801 \times 10^{-1}$	73,350	4,550
	Quadrado	$4,080 \times 10^{-4}$	2,213	150,818
$2,794 \times 10^{-6}$	Hexagonal	$6,067 \times 10^{-4}$	2,810	118,776

In Table (3) are presented the results for six configurations of vacuum tables where can be noted that all configurations meet the Von-Mises criterion . Therefore, two other criteria were used to elect the best vacuum table configuration for this machining . The first criterion used was the stiffness/weight ratio by applying Eq. (2) determining the highest value (Paiva, Silva and Lima Jr, 2010b). The Table (4) presents the results.

$$\frac{K}{P}=\frac{F}{\delta.P} \tag{2}$$

Where:

K - Stiffness (N/mm)
F - Force applied (N)
δ - Displacement (mm)
P - Weight (N)

Table 4 – Ratio of stiffness/weight

Vaccum table dimension	**Material / Density (kg/mm^3)**	**Core**	**Volume table (mm^3)**	**Weight table (N)**	**K/P (1/mm)**
150 x 150 mm	AISI 1005 (7,872 x 10^{-6})	Vazado	112035,3025	8,82	1,231 . F1
		Quadrado	152264,6832	11,99	386,124 . F1
		Hexagonal	149089,6495	11,74	258,745 . F1
140 x 140 mm	Alu. 2014 (2,794 x 10^{-6})	Vazado	100138,5275	2,80	1,983 . F2
		Quadrado	137167,9082	3,83	639,943 . F2
		Hexagonal	136005,1075	3,80	433,752 . F2

*g = 10 m/s^2 (gravitity)

As shown in Tab. (4), the highest ratios of stiffness/weight determine the lowest weight of the vacuum table without compromising its stiffness, which, however, are more favorable to the table 140 x 140 mm of aluminum 2014. However, for the same pressure differential of 100 kPa applied to two different sizes of vacuum tables result in different magnitudes of forces, denoted by F1 and F2 that are related to the contact areas of the vacuum table and an atmospheric pressure. In this case, the complexity of the geometry of the vacuum table made it difficult to determine the magnitudes of F1 and F2 applied to the relationship of stiffness/weight, precluding a direct comparison between the tables of 150 x 150 mm of steel and 140 x 140 mm of aluminum. To ensure the same force F1 in the comparison of the stiffness/weight ratio between steel and aluminum to the table 150 x 150 mm, in order to determine which one is right, he was admitted a vacuum table 150 x 150 mm of aluminum 2014, according to results presented by Tab. (5) (Paiva, Silva and Lima Jr, 2010b). Given the comparison of Tab. (5) was observed that even with higher deformation, the aluminum had the highest ratios stiffness/weight and also had approximately 1/3 the weight of steel. Thus, the most appropriate material for the construction of tables vacuum is aluminum. Therefore, by the criterion of stiffness/weight ratio the aluminum table of 140 x 140 mm was selected.

Table 5 – Comparison between steel and aluminum to the table 150 x 150 mm

Material	**Core**	**Maximum displacement (mm)**	**Maximum stress (MPa)**	**Safety factor**	**Weight table (N)**	**K/P (1/mm)**
AISI 1005	Vazado	9,209 x 10^{-2}	67,240	3,361	8,82	1,231 . F1
	Quadrado	2,160 x 10^{-4}	2,499	90,436	11,99	386,124 . F1
	Hexagonal	3,292 x 10^{-4}	3,239	69,774	11,74	258,745 . F1
Alu. 2014	Vazado	2,414 x 10^{-1}	65,830	5,070	3,13	1,323 . F1
	Quadrado	5,730 x 10^{-4}	2,720	122,707	4,25	410,635 . F1
	Hexagonal	8,713 x 10^{-4}	3,458	96,519	4,17	275,230 . F1

The second selection criterion, which stipulates that the nucleus has the best homogeneity of the internal vacuum, was applied taking into consideration the stiffness/weight ratio core geometry. The most manufacturers of vacuum tables surveyed affirm that hexagonal cores have a better distribution of indoor air that helps create the vacuum more homogeneous across the table. For optimization of the selected table, other results have been verified, and it was found that the smaller the perimeter of the square or hexagonal core, the stiffness /weight ratio increases considerably, and the difference between the core of this relationship is diminished, so this shows yet another advantage the use of core hexagonal tables in use in vacuum. The Table (6) presents the final results, choosing as the table of aluminum 2014, 140 x 140 mm, with hexagonal core and perimeter of 58.90 mm (Paiva, Silva and Lima Jr, 2010b).

Table 6 – Final results

Tables / Material	**Core**	**Core perimeter (mm)**	**Maximum displacement (mm)**	**Maximum stress (MPa)**	**Weight table (N)**	**K/P (1/mm)**
140 x 140 mm Alu. 2014	Hexagonal	109,09	6,067 x 10^{-4}	2,810	3,80	433,752 . F2
140 x 140 mm Alu. 2014	Hexagonal	58,90	9,324 x 10^{-5}	0,979	4,43	2420,995 . F2

5. CONCLUSIONS

This paper presented the fundamentals of vacuum technology and its main applications in precision engineering. It was observed that the controlled atmosphere, that the vacuum technology provides, has enabled the evolution of many manufacturing and measuring processes. Manufacturing of complex devices, miniaturization, high accuracy, better surface finishing, speed and flexibility are the main motivations of the use of vacuum technology. This makes it an important and indispensable technology to the modern world.

In this work, the vacuum technology was applied in the design and development of vacuum tables, by using materials like steel and aluminum, in order to replace the traditional fasteners used in machine tools. The results showed that the vacuum tables are capable of fixing workpieces in milling processes. The tables make from aluminum with reduced hexagonal cores showed better results as it enables a reduction in weight and size of the table without reducing its stiffness, as well as providing a more uniform vacuum distribution inside of its core.

The package NX NASTRAN 7.0 was essential for design, development, simulation and analysis of vacuum tables, since it allowed an objective and clear understanding of the most effective and appropriated vacuum table configuration, totally replacing a analytical solution, which in this case, it is not feasible due to complexity of geometry, loads and the amount of parameters involved.

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