INVESTIGATION OF CLAMPING ON A CNC ROUTER

Etele Csanády – Szabolcs Németh

Abstract

Computer controlled machining equipment and centres that provide accuracy in the thousandth millimeter range, represent the pinnacle of woodworking technology. When cutting happens and, as a consequence, forces act in several different directions. For micrometer precision control of the cutting tool, workpieces have to be fastened securely, deprived from their degrees of freedom, to achieve maximum quality. The most frequent clamping method for pieces with planar surfaces today is fastening by a vacuum field. The vacuum-induced hold-down force, together with μ_0 and μ (static and kinetic friction coefficients, respectively) creates the friction force that prevents the workpiece from shifting. The purpose of our numerous measurements was the analysis of the workpieces' movement. The shifting of the material upon intensive cutting or at the start of the cutting process is a frequent problem.

Key words: *clamping, CNC router, vacuum, forces*

INTRODUCTION

In the past decade, CNC processing centres made a widespread appearance in the woodworking industry. While previously wood material used to be fed into the machines, usually at considerable rates, now the material is fixed and the cutting head or the clamping table moves on the desired track. The structural design of the cutting head and table allows a maximum of three translation and three rotational movements. In reality, most machines - performing planar processing only - have no more than two and a half degrees of freedom. When manufacturing seat components are included, four degrees of freedom are necessary. Because in this case edges almost always have to be cut or profiled all-around, traditional clamping methods are inadequate. Thus, vacuum clamping was created, primarily for planar surfaces. Our measurements were carried out on a solid raster table, where vacuum was created in rubber-profile-bordered chambers. Secure fastening of the work piece is required for accurate cutting; without this the μm precision of the control and mechanical system is futile. Occasional shifting or slipping of the material causes inaccurate geometry and poor surface quality. This was the focus of our investigations. The woodworking industry strives for a higher throughput that necessitates high feed rates and cutting speeds that, in turn, intensifies the dynamic loads acting in various directions. It is imperative to investigate the limits of the work piece's stability with regards to shifting and vibration.

1. THEORETICAL CONSIDERATIONS

Measurements were carried out on a raster vacuum table as described in the introduction. The clamping table's surface contains grooves, arranged in a chequered pattern. A vacuum area of the desired size and shape may be formed by placing rubber profiles in the grooves. The good condition of the vacuum pump allowed a maximum of – 0,9 bar vacuum to be created. Clamping is achieved through creating vacuum in the very small gap between the work piece and the table. This vacuum, together with the negligible gravitational forces, creates the force that presses the surfaces to one another.

$$F_{vacuum} = p_{vacuum} \cdot A$$

A – surface; p_{vacuum} – vacuum pressure; F_{vacuum} – the force pressing the surfaces to one another

Vacuum force is linearly proportional to two parameters: surface area, and vacuum pressure. During the measurements, we gradually decreased the value of both parameters, and shifted the materials. The piece will not shift as long as the cutting forces do not reach or exceed the static friction force.

2. EXPERIMENTAL METHODS

According to theoretical considerations, we had to construct a measurement circuit that measures displacement in the μm range, and is capable of measuring static and kinetic friction forces.

2.1 Shifting the work piece secured by vacuum

Fig. 1 shows the work piece on the raster table. The work piece contained a vacuum gauge and coarse and fine control valves, for vacuum control. It was dragged using an electric motor-driven worm-gear spindle and joint mechanism. The load cell mounted between the joints is clearly visible on the figure. The measurement and registration of displacement, as well as that of load, was essential.

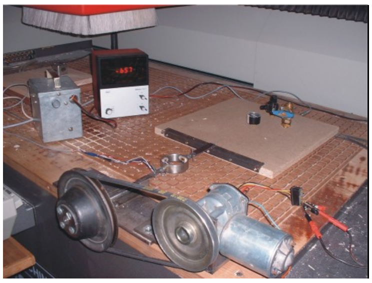

Fig. 1 Specimen with the dragging mechanism

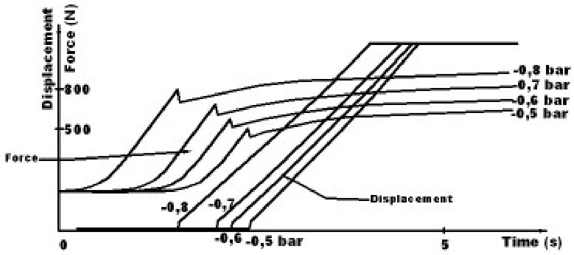

Fig. 2 Load and displacement plot of a laminated particleboard

Load and displacement were measured simultaneously, using a given vacuum surface and different vacuum pressure levels, as shown on Fig. 2. It is clear that the nonlinearly increasing load falls suddenly back upon shifting. After this, sliding begins, and the load slowly, nonlinearly approaches a maximum value. A third database came from measuring surface roughness.

2.2 Shifting weighed-down work pieces on the raster table

Fig. 3 Shifting a weighed-down work piece on the raster table

Fig. 4 Work piece pull of apparatus with load cell

In the second measurement system, gravitational load was substituted for vacuum pressure, as shown on Fig. 3. The raster table was examined under these conditions two different ways: with and without the rubber profile, even though vacuum pressure was not applied. The goal was simply to observe how the rubber profile affects the friction.

2.3 Lifting the work piece off the raster table vertically

The pull off apparatus (Fig. 4.) is capable of ripping a 400x400 mm panel off the vacuum raster table.

This third type of measurement investigates one of the most critical parameter of vacuum clamping, namely, what portion of the rubber-profile-bordered area acts as an effective vacuum zone.

2.4 Dynamic impact testing of vacuum-clamped specimens

The equipment shown on the above picture, created based on a location energy principle, was used for modelling dynamic loads that best approximate those generated when cutting. Preset parameters included location energy, vacuum and clamping surface area. Measured parameters included the shifting distance of the plate and the shift function in the 0-2 mm domain.

Fig. 5 Completed impact testing equipment

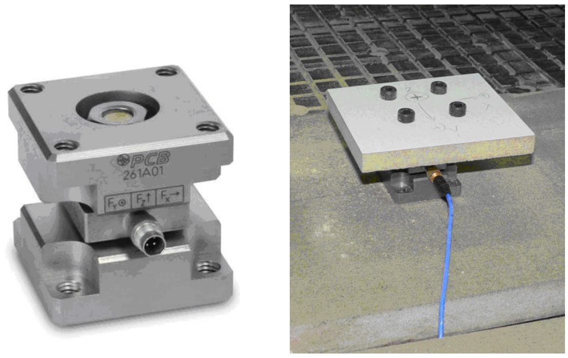

Fig. 6 ICP® 3-Component Force Link

2.5 Measuring cuting force

The measurement took place by a three direction force measuring cell (fig. 6.). PCB Piezotronics 3-component force link sensors are designed to simultaneously measure dynamic and quasistatic force measurements in three orthogonal directions; Fx, Fy and Fz. We used two piece of tools, both two-barrelled, one straight mantle miller and one aslope mantle miller, see on fig. 7.

Fig. 7 Tools

On the work pieces (oak, beech, MDF) clamped to the cell we made countermarch cuts.

3. RESULTS

The evaluation of the shifting studies included the following physical and mechanical parameters for both vacuum clamping and weighing down:

Static friction coefficient: $\mu_0 = p_{drag1} / p_{vacuum}$ $p_{drag1} = F_{shift} / A$

Kinetic friction coefficient: $\mu = p_{drag2} / p_{vacuum}$ $p_{drag2} = F_{slide} / A$

- Shifting load (F_{shift}) is the force required to shift the stationary piece.
- Sliding load (F_{slide}) is the force required for the continuous sliding of the piece

3.1 Shifting the work piece secured by vacuum

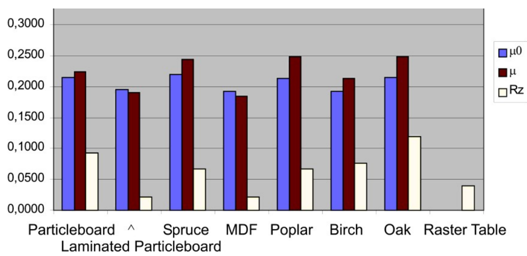

Fig. 8 The values of μ, μ_0 and R_z of various materials, when moving the pieces across the grain, at –0.7 bar and 0.0656 m^2

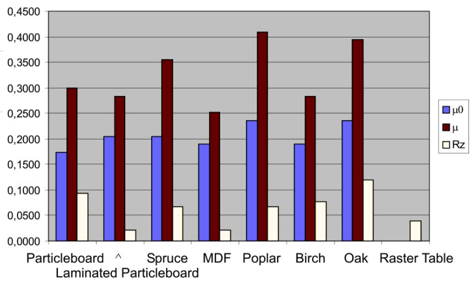

Fig. 9 The values of μ, μ_0 and R_z of various materials, when moving the pieces across the grain, at –0.2 bar and 0.0365 m^2

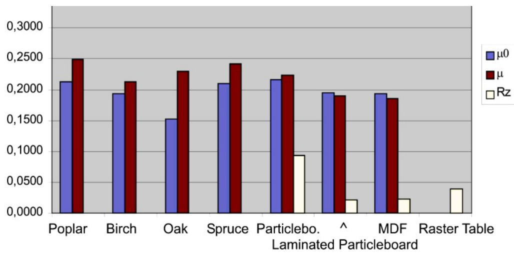

Fig. 10 The values of μ, μ_0 and R_z of various materials, when moving the pieces along the grain, at –0.7 bar and 0.0656 m^2

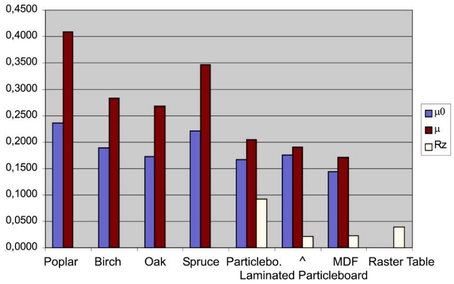

Fig. 11 The values of μ, μ_0 and R_z of various materials, when moving the pieces along the grain, at –0.2 bar and 0.0365 m^2

Based on diagrams, most of the results do not conform to the roughness classification of the species, in case of normal clamping (0.6-0.8 bar). This is because, during clamping, the surfaces are pressed to one another and suffer distortions in the μm range. The situation is more complex than to be described by simple rules of physics, because of the elastic, adhering, slowing effect of the rubber profile.

The bar charts also indicate that static friction coefficient is only slightly, while kinetic friction coefficient is very dependent on pressure and surface area.

3.2 Shifting weighed-down work pieces on the raster table

Investigations using gravitational load produced results very similar to those of the previous (vacuum) measurement. Fig. 12. and 13. show that the presence of the rubber profile resulted in the same, reverse situation as the vacuum study, i.e. the kinetic friction coefficient is only slightly higher than the static one, when using substantial loads. Differences are more pronounced when using smaller loads.

Fig. 14. and 15. prove conclusively that order is restored as soon as no rubber profile is used, and classic static and kinetic friction conditions prevail.

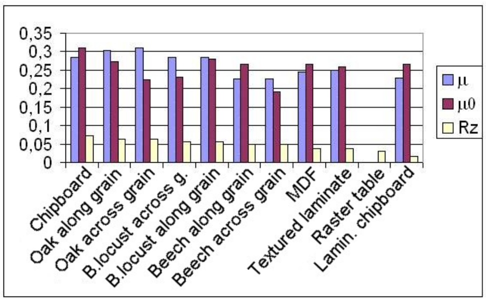

Fig. 12 The values of μ,$\tilde{\mu}_0$.and R_z of various materials, in order of decreasing roughness, measured on a 0.0723 m^2 surface area and using a load corresponding to –0.6 bar vacuum pressure, using rubber profiles

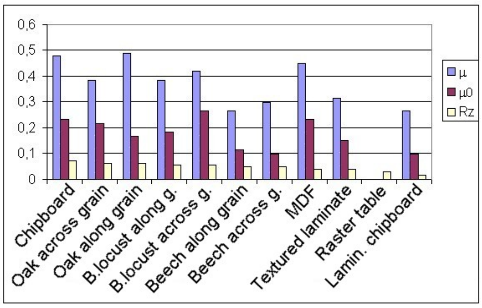

Fig. 13 The values of μ, μ_0 and R_z of various materials, in order of decreasing roughness, measured on a 0.0302 m^2 surface area and using a load corresponding to –0.2 bar vacuum pressure, using rubber profiles

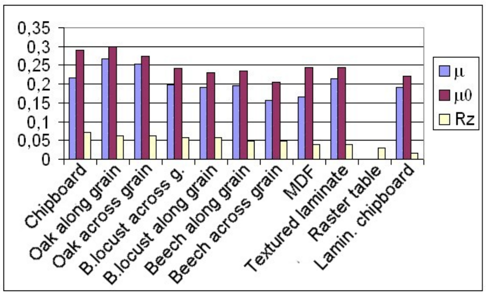

Fig. 14 The values of μ, $\tilde{\mu}_0$ and R_z of various materials, in order of decreasing roughness, measured on a 0.0723 m^2 surface area and using a load corresponding to –0.6 bar vacuum pressure, without rubber profiles

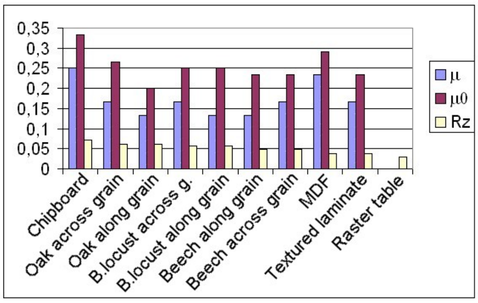

Fig. 15 The values of μ, μ_0 and R_z of various materials, in order of decreasing roughness, measured on a 0.0302 m^2 surface area and using a load corresponding to –0.2 bar vacuum pressure, without rubber profiles

3.3 Lifting the work piece off the raster table vertically

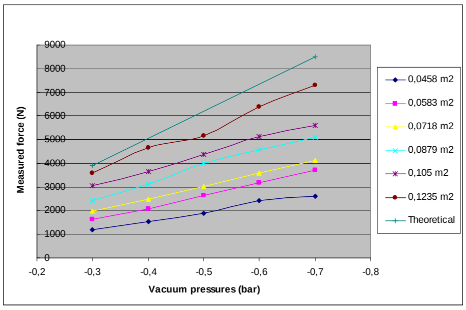

Fig. 16 The relationship between pull off force and vacuum pressures using chipboard with various clamping surface areas

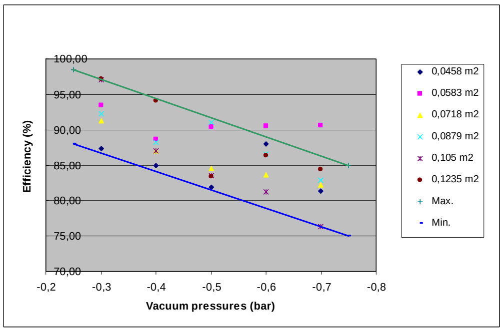

Fig. 17 The relationship between the efficiency, calculated as the ratio of pull off force to theoretical force, and pressure, using chipboard with various surface areas

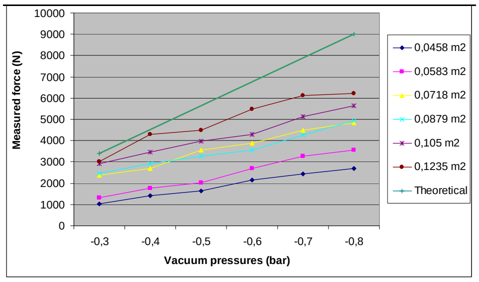

Fig. 18 The relationship between pull off force and vacuum pressures using MDF with various clamping surface areas

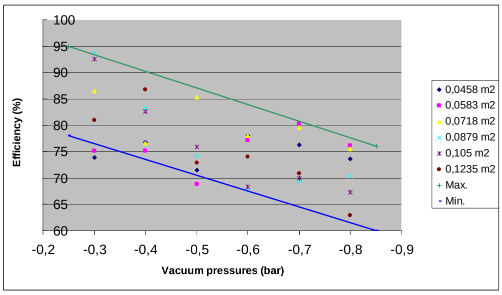

Fig. 19 The relationship between the efficiency, calculated as the ratio of pull off force to theoretical force, and pressure, using MDF with various surface areas

The third measurement series produced the expected results. The area of the raster table sealed off for producing vacuum should not be regarded 100% effective vacuum area.

In case of chipboard and MDF (Figures 16. and 18.), the clamping force decreases almost linearly with decreasing vacuum pressure. Fig. 17. and 19. show the clamping efficiency functions for chipboard and MDF, its initial value being 85% and 75%, respectively. The lack of trend, immediately apparent in the diagrams, is due to losses. Further investigations are needed to achieve more accurate results. However, the improvement in efficiency at lower vacuum pressures is clear.

3.4 Results of the dynamic tests of vacuum-clamped specimens

For dynamic testing, the primary issue was the analysis of the shifting process. Shift curve characteristics were different at various vacuum values and location energies, but the basic character was similar:

- horizontal section: a state of rest, when no external force affects the specimen
- a short curve: the specimen leaves its resting position
- a nearly linear section: most of the specimen's movement occurs in a short time.
- the function begins to undulate. The specimen is supported on elastic rubber, which causes it to slide erratically
- the undulations start to lessen and the specimen returns to a resting state.

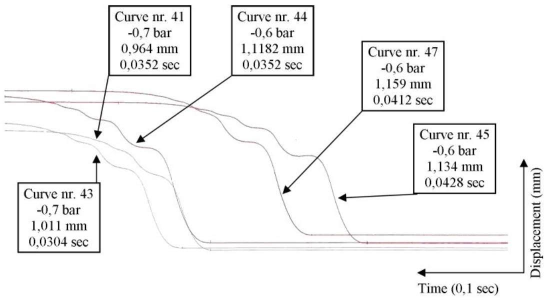

Fig. 20 The displacement of oak as a function of time. Drop: 7.5 cm.

The rubber profile clearly changes the conventional character of sliding. The measurement data was analysed to establish the portion of the original potential energy that is converted into actual work realised as specimen displacement. The results were as shown on the fig. 21.

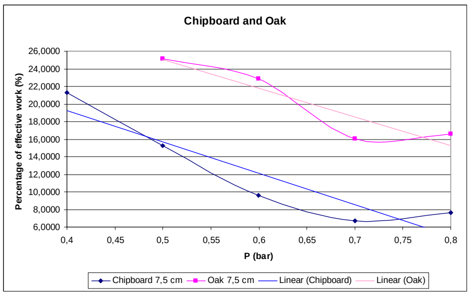

Fig. 21 The percentage of effective work at various vacuum values and equal heights, in the case of chipboard and oak.

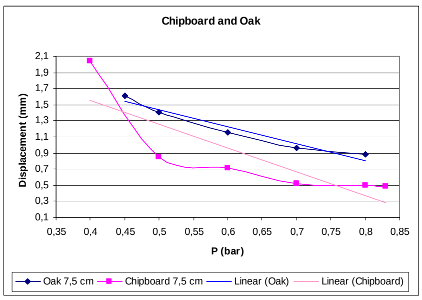

Fig. 22 The displacement of oak and chipboard at various vacuum values and 7.5 cm dropping distance

The curve analysis revealed two surprising results:
- the low proportion of effective work damping is high and the energy is lost in the elastic impact.
- better effectiveness and more displacement may be generated at lower vacuum, because the clamping force is lower and the elasticity of rubber subverts the physical principles.

The displacement diagrams of the same test are shown on the fig. 22.
Lower vacuum values obviously yielded larger displacements.

3.5 Results of 3-components force measuring

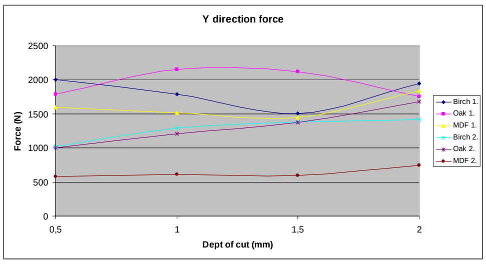

Fig. 23 Y direction force

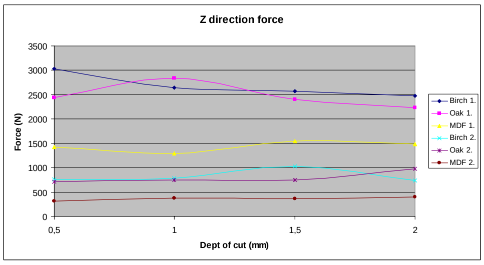

Fig. 24 Z direction force

1-st measuring is with straight mantle miller, and 2-nd measuring is with aslope mantle miller.
The vacuum based fixing of the work pieces is flexible, this allows an oscillating system. Because of the heterogen structure of the wood, the force measurements showed that even by using straight mantle miller there is a Z direction force with variable amplitude; this is showed on fig. 24. In case of an aslope tool the creeping cutting character appears, this cuts the Y direction clamping force back, see on fig. 23., and it enlarges the Z direction force, see on fig. 24.

4. CONCLUSIONS

The discussed problem is a new issue in the industry. It is very important, because clamping has a significant effect on cutting accuracy. Resulting diagrams show that drawing general rules is fairly difficult. This is due to the fact that the issue at hand is not a simple surface contact problem, but a complex, partly elastic clamping system. When approximating the dynamic model of cutting tools, considerable energy loss occurs due to damping losses. However, even this low percentage of effective energy is enough for shifting the work piece.

REFERENCES

[1] Hoffmann, W., Vacuum clamping for CNC-woodworking, Holz als Roh- und Werkstoff 50, Springer-Verlag, 1992.
[2] Kiss, J. G., *MSc. Thesis*, Work piece clamping on a CNC router, UWH, Sopron, 2002.
[3] Vass, G., *MSc. Thesis*, Vacuum clamping of work pieces, UWH, Sopron, 2003.
[4] Krabácz, G., *MSc. Thesis*, Investigation of vacuum clamping, UWH, Sopron, 2004.
[5] Szécsi, I., *MSc. Thesis*, Investingation of forces in vacuum clamping on CNC processing centres, UWH, Sopron, 2005
[6] Rumpler, T., *MSc. Thesis*, Investigation of vacuum clamping dynamic, UWH, Sopron, 2007.