INVESTIGATION OF CLAMPING ON A CNC ROUTER

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Abstract

Computer controlled machining equipment and centres that provide accuracy in the thousandth millimeter range, represent the pinnacle of woodworking technology. Cutting happens and, consequentially, forces act in several different directions. For micrometer precision control, workpieces have to be fastened securely, to achieve maximum quality. The most frequent clamping method for pieces with planar surfaces today is fastening by vacuum. The vacuum-induced hold-down force creates a friction force that prevents the workpiece from shifting.

The purpose of our 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. Vacuum pressure value, clamping surface area, movement direction compared to fibre orientation were being varied throughout the measurement, and various wood species were used. All of these parameters affected μ_0 and μ. This change did not always seem to follow the rules of physics, because our measurements did not involve clear friction. The rubber profile enclosing the vacuum compartment influenced the conditions after shifting significantly. Specimen deformation due to compression forces might also have affected the results. The measurements have also shown that adherence of the pieces is related to surface roughness, although there were exceptions, too.

Key words: *CNC, woodworking, clamping, vacuum*

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 a desired track. The structural design of the cutting head and table allows a maximum of three translation and three rotational movements. In reality, most machinery – performing planar processing only – have no more than two and a half degrees of freedom. When manufacturing seat components, four degrees of freedom are necessary. Considering that 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 workpiece is a condition of 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. The above topic was at the center of our investigations. 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 workpiece's stability with regards to shifting and vibration.

Theoretical considerations

Measurements were carried out on a raster vacuum table as described in the introduction. The table has square pattern grooves. 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. The basis of the clamping is creating vacuum in the very small gap between the workpiece and the table. This vacuum, together with the negligible gravitational forces, creates the force that presses the surfaces together.

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

A – surface

p_{vacuum} – vacuum pressure

F_{vacuum} – the force pressing the surfaces together

Vacuum force is linearly proportional to two parameters. One is the surface area, the other is the vacuum pressure. During the measurements, both parameters were changed; the vacuum was weakened, the surface decreased, and the different materials shifted along and across the grain.

The piece won't move as long as the cutting forces don't reach or exceed the static friction force.

EXPERIMENTAL METHODS

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

Shifting the workpiece secured by vacuum

Force measurement happened indirectly, through measuring deformation. Figure 1 shows the workpiece on the raster table. The workpiece 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. Extension gauges connected in a Wheatstone bridge were mounted inside the load cell.

The measurement and registration of displacement, as well as that of load, was essential.

The output signal of the displacement gauge was connected to the second channel of the plotter, thus simultaneous registration of load and displacement was possible. Some sample graphs are shown on Figure 2.

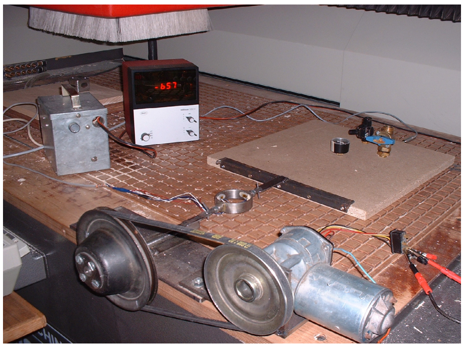

Figure 1 – Specimen with the dragging mechanism

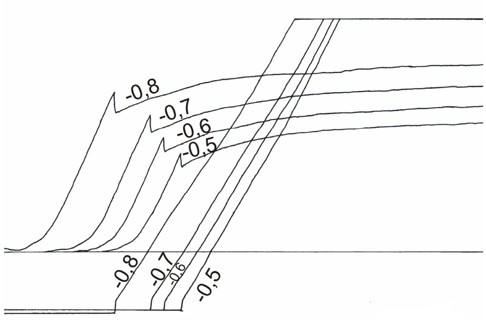

Figure 2 *– Load and displacement plot of a laminated particleboard*

Tests included various wood species and products, including spruce (*Picea abies*), poplar (*Populus* spp.), birch (*Betula pendula*), oak (*Quercus* spp.), particleboard, MDF and laminated particleboard. In each case, vacuum pressure was adjusted between 0.2 and 0.9 bar, in 0.1 bar increments. The surface area changed between 0.0365 to 0.0729 m^2, in six steps.

As shown on Figure 2, using a given vacuum surface and four different vacuum pressure levels, load and displacement were measured simultaneously. 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. Measurements lasted only 20 to 30 seconds.

A third database came from measuring surface roughness.

The parameters affecting the surface quality of wood are the following:

1. Roughness generated by mechanical processing:
   - kinematical roughness,
   - roughness caused by the macro and micro geometry of the cutting tool,
2. Anatomical roughness.

Shifting weighed-down workpieces on the raster table

In the second measurement system, gravitational load was substituted for vacuum pressure, as shown on Figure 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 friction theory.

Lifting the workpiece off the raster table vertically

The pullof apparatus (Figure 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.

***Figure 3** – Shifting a weighed-down workpiece on the raster table*

***Figure 4** – workpiece pullof apparatus with load cell*

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:	$\mu = p_{drag2} / p_{vacuum}$	$p_{drag2} = F_{slide} / A$
Ratio of shifting load to sliding load:	F_{shift} / F_{slide}	
The ratio of load fluctuation to sliding load:	$\Delta F / F_{slide}$	

- Shifting load (F_{shift}) means the force required to shift the piece.
- Sliding load (F_{slide}) means the force required for the continuous sliding of the piece
- Load fluctuation (ΔF) is the change in load during sliding.

Shifting the workpiece secured by vacuum

Change in static friction coefficient (μ_0)

When adjusting the vacuum pressure, keeping the area constant, an inverse relationship was found between the pressure and μ_0, except when dragging across the grains. μ_0 decreases slightly with increasing pressure, due to surface layer deformation.

Similarly to μ_0, the tendency is that vacuum pressure is inversely proportional to μ, i.e. higher vacuum results in lower μ values, both parallel and perpendicular to the grain, due to surface layer deformation.

Figures 5 and 6 show μ_0, μ and R_z (the latter shown on a relative scale) in the same diagram, for transverse movement, at two different sets of clamping parameters

Figures 7 and 8 show μ_0, μ and R_z (the latter shown on a relative scale) in the same diagram, for logitudinal movement, at two different sets of clamping parameters.

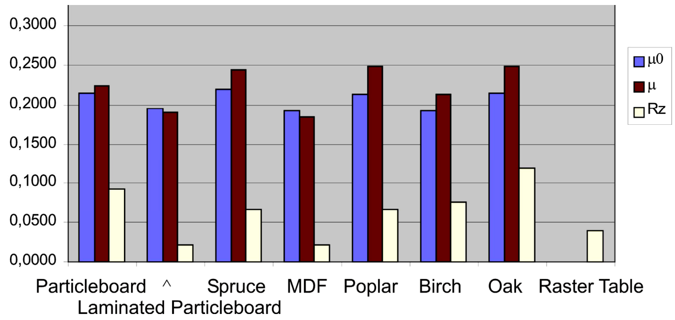

Figure 5 *– The bar chart shows the value of μ, μ_0 and R_z, depending on species, when moving the pieces across the grain, at –0.7 bar and 0.0656 m^2*

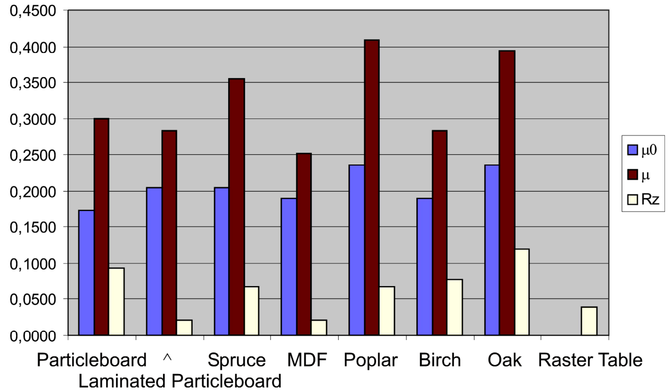

Figure 6 *– The bar chart shows the value of μ, μ_0 and R_z, depending on species, when moving the pieces across the grain, at –0.2 bar and 0.0365 m^2*

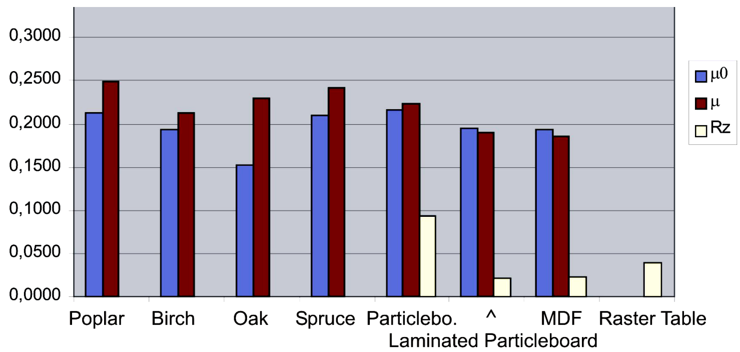

Figure 7 *– The bar chart shows the value of μ, μ_0 and R_z, depending on species, when moving the pieces along the grain, at –0.7 bar and 0.0656 m^2*

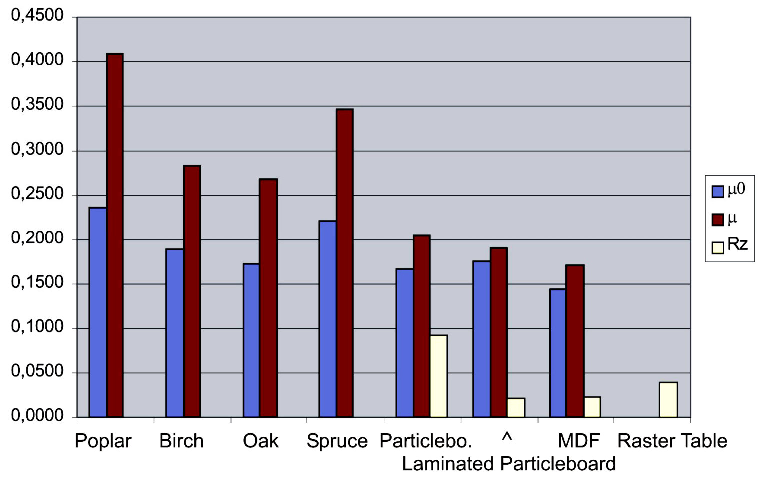

Figure 8 *– The bar chart shows the value of μ, μ_0 and R_z, depending on species, when moving the pieces along the grain, at –0.2 bar and 0.0365 m^2*

In Table 1, the species are in order of increasing roughness. The symbols show whether the value of μ_0 and μ were in accordance with their roughness classification.

Based on this table, 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 together 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.

Table 1 *– The behavior of various materials as compared to their roughness classification*

	Along the grain		Across the grain	
	μ_0	μ	μ_0	μ
Laminated Pricleboard	—	—	—	—
MDF	—	+	O	+
Poplar	—	—	O	—
Spruce	—	—	—	—
Birch	+	+	+	+
Pricleboard	+	+	O	+
Oak	+	+	+	+

+ *Slides better than expected based on roughness classification*

— *Slides worse than expected based on roughness classification*

O *Normal; behaves according to the roughness classification*

Shifting weighed-down workpieces on the raster table

Investigations using gravitational load produced exactly the same results as the previous (vacuum) measurement method. Figures 9 and 10 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.

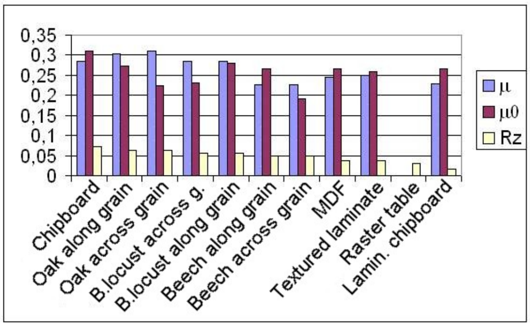

***Figure 9** – Bar chart showing the order of μ,μ_0 and R_z, according to species, using rubber profiles, measured on a 0.0723 m^2 surface area and using a load corresponding to -0.6 bar vacuum pressure.*

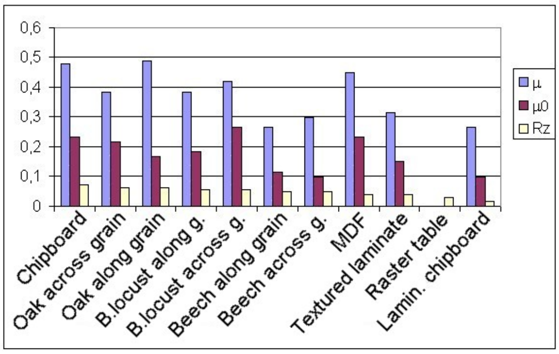

***Figure 10** – Bar chart showing the order of μ, ,μ_0, and R_z, according to species, using rubber profiles, measured on a 0.0302 m^2 surface area and using a load corresponding to -0.2 bar vacuum pressure.*

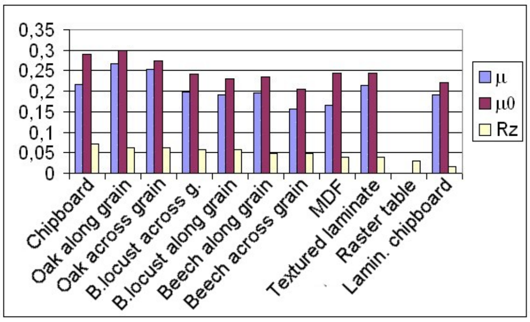

***Figure 11** - Bar chart showing the order of μ,μ_0 and R_z, according to species, without rubber profiles, measured on a 0.0723 m^2 surface area and using a load corresponding to -0.6 bar vacuum pressure.*

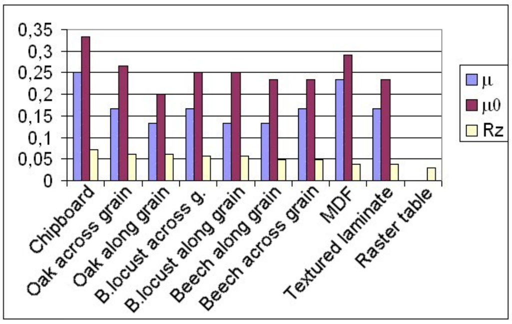

Figure 12 *– Bar chart showing the order of* μ, μ_0 *and* R_z*, according to species, without rubber profiles, measured on a 0.0302* m^2 *surface area and using a load corresponding to -0.2 bar vacuum pressure.*

Figures 11 and 12 prove conclusively that order is restored as soon as no rubber profile is used, and classic static and kinetic friction conditions prevail.

Lifting the workpiece off the raster table vertically

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. According to the preliminary measurement results on Figures 13 - 16, the effective vacuum area is 70 to 90 % and 40 to 54 % in the case of laminated chipboard and laminated MDF, respectively. To establish general principles, much more species should be involved in this study. However, the study is conclusive in that only part of the vacuum area is effective.

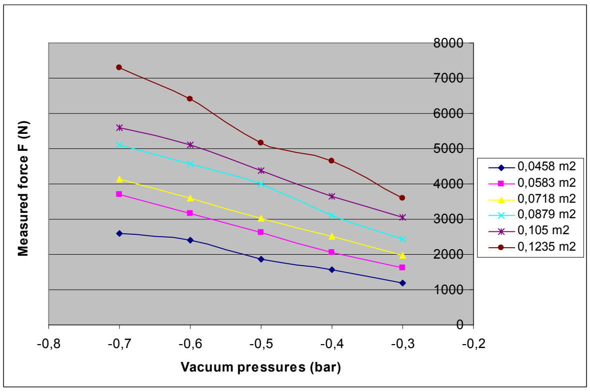

Figure 13 *– The relationship between pull off load and vacuum pressures at various clamping surface using chipboard*

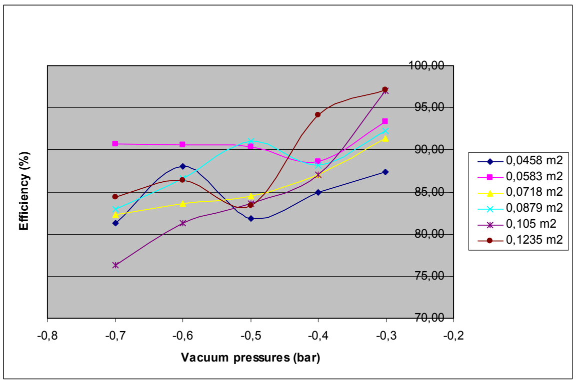

Figure 14 *– The relationship between the efficiency, calculated as the ratio of pull off force to theoretical force, and pressure, using chipboard with various surface areas.*

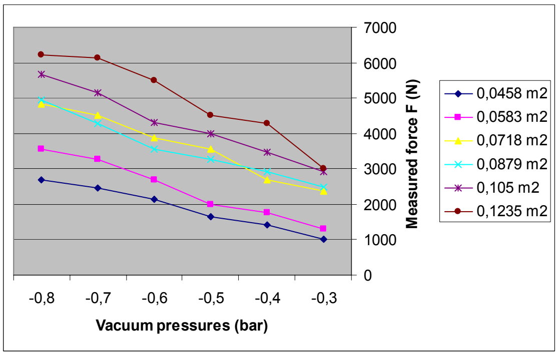

Figure 15 *– The relationship between pull off load and clamping surface at various vacuum pressures using MDF*

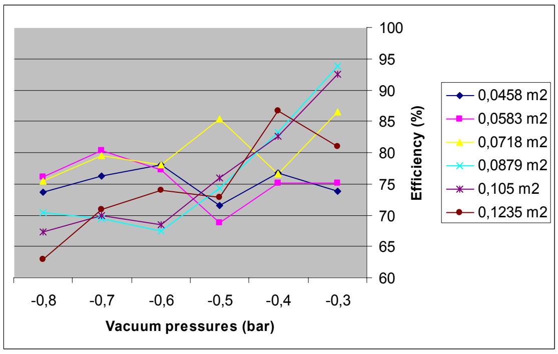

Figure 16 *– The relationship between the efficiency, calculated as the ratio of pull off force to theoretical force, and pressure, using MDF with various surface areas.*

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.

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