DAMPED TOOL PERFORMANCE EVALUATION IN DIE POCKETS MILLING

Helder Barbieri Lacerda, helder@mecanica.ufu.br
Federal University of Uberlandia, Mechanical Engineering School, Joao Naves de Avila Av., 2121, 1M block, 38408-100, Uberlandia, MG, Brazil.

Paulo Rosa da Mota, prmota@mecanica.ufu.br
Federal Centre for Technological Education – CEFET-GO, 75th Street, 46, 74055-110, Goiania, GO, Brazil.

Abstract. Die pockets milling is a difficult task because the machined material has high hardness and the tool has high length / diameter ratio, low stiffness and small capacity to absorb the resulting vibrations. In order to achieve good quality surface and avoid chatter vibrations, the cutting parameters are chosen conservatively, reducing the operation productivity. Damped tools have an internal damping system, which reduces vibrations and enables higher axial depth of cut in order to increase the chip removal rate. This work objective is to compare the performance of one damped tool with another with the same size, but without the internal damping system. The measured variables were the vibration levels during the cut and the resulting machined part surface rugosity. The paper gives to reader useful information in order to evaluate the damped tool cost-benefit ratio in die pockets milling.

Keywords*: Milling, chatter, damping, anti-vibration tool.*

1. INTRODUCTION

The Brazilian die and mould sector has an estimated annual production of US$600 million, but about 2/3 of this value correspond to imported products. The sector seeks to increase the technological and competitive capacity in order to reduce prices and time of delivery, comparing with international competitors. According to Vallejos & Gomes (1998) *apud* Resende & Gomes (2004), about 60 to 70% of higher complexity and height moulds (like those of the automobile industry) are imported and the small and simple moulds are ordered from internal manufacturers, who usually put the technological innovation and efficiency in the background. Nevertheless, machine tool builders, software developers and cutting tool dealers have made efforts to change this situation in behalf of the die and mould sector, presenting several newness during fairs and events.

One of these newness are tools which have an internal damping system, consisting of a lead mass supported by two rubber bushes, immersed in a viscous oily fluid, which introduces damping. Figure 1 contains pictures showing the internal vibration damping systems for turning and milling of cavities in dies and moulds. The objective of this work is to compare the performance of a silent tool with another of the same size, but without the internal damping system. The measured variables were the vibration amplitude during the milling of cavities in VP40® steel and the superficial rugosity of the machined part. Several combinations of feed and cut depth were utilized in order to cover a large bandwidth. The results show good performance of the damped tools, but there are some restrictions.

2. MATERIALS AND METHODS

The methodology was simple, consisting in the comparison of the vibration signal levels, measured at the machining centre main bearing spindle, for each tool during tests performed with the same cutting parameters. The machined material is the VP40® steel by Villares Metals, with Rockwell C 30 hardness. This steel is very used for die and mould manufacture, because it is easy to machine, weld and polish. It also has high corrosion and wear resistance and is undeformable with the time. Table 1 shows the material chemistry composition.

Table 1 – VP40® steel chemistry composition (mass percentage, extracted from Pinedo (2004))

C	Si	Mn	Cr	Mo	V	Ni	Al	Cu	Ti	Co
0,17	0,40	1,54	0,29	0,26	--	2,92	0,98	1,00	--	--

The machine tool is the machining centre ROMI Discovery® 760, with 11 kW power and 10 to 10.000 rpm speed range. Figure 2 shows the machine and the tool (set: adaptor, inserts holder and inserts) used in the experimental tests. Table 2 shows the adaptors and inserts specifications. Both the tools have the same external aspect and dimensions, but the anti-vibration tool is 19% heavier.

The machined surface rugosity was measured by using a Taylor-Hobson Surtronic 3+ rugosimeter (http://www.taylor-hobson.com.uk). The work-piece surface was initially flattened to guarantee uniform cut depth for all the tests. The tests sequence was the same for both tools. Several combinations of feed, cut depth and tool rotation speed were selected, respecting the suggested limits written in the inserts maker catalogue. Table 3 shows the cutting parameters employed in the tests. An accelerometer B & K 4501A and conditioner NEXUS 2692 (http://www.bk.dk) were employed to measure the vibration at the machining centre main bearing spindle, in the X-axis positive direction. The vibration signal was acquired by using a National Instruments (http://www.natinst.com) PCI6035E data acquisition board, installed into a microcomputer running at 950 MHz, with 1GB RAM memory. The selected sampling speed was 12 KHz. Table 4 shows the main characteristics and settings of these instruments.

Table 2 – Adaptors and insert specifications

Item	Specification	Mass (Kg)
Common adaptor	S-C5-391 TD-12 186	1.225
Anti-vibration adaptor	C5-391 TD-12 186	1.460
Insert	R216-20T3M-M SM30	-----

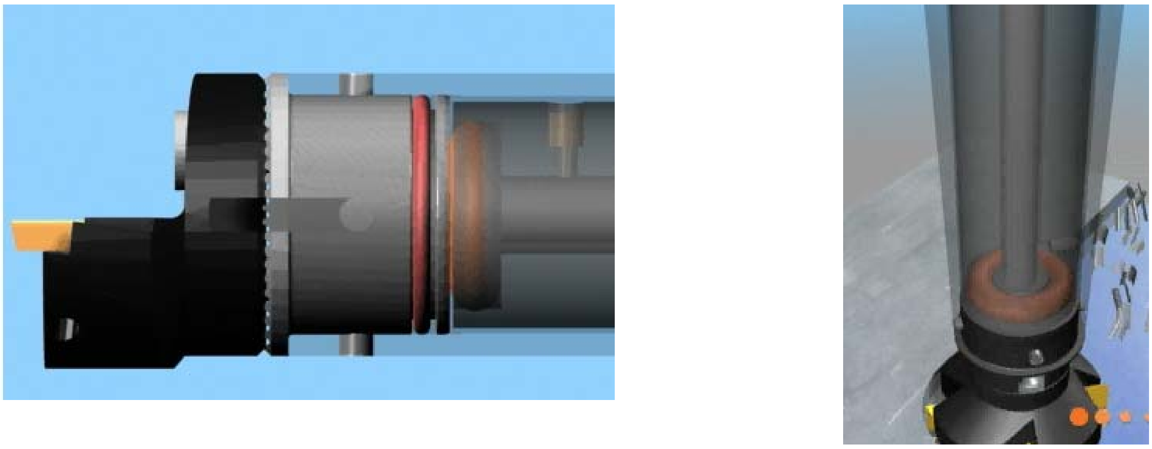

Figure 1 – Turning and milling tools with internal anti-vibration system (extracted from dealer catalogue)

Figure 2 – ROMI Discovery 760 machining centre and anti-vibration tool.

Table 3 – Milling tests cutting parameters

Parameter	Value	Observations
Tool rotation speed range	1000 to 4000 rpm	Maximum speed is 6000 rpm.
Feed f_z	0.1 mm/tooth	Adopted. The maximum is 0,2 mm/tooth.
Chip load: $f_c = f_z \cdot N$	0.2 mm/revolution	N = 2 teeth
Feedrate	$f_c \times n$ [mm/min]	Calculated in order to keep constant chip load.
Cut width	12.5 mm	Adopted in order to have only one tooth cutting at one time.
Cut depth	1 and 2 mm (roughing) 0.3 mm (finishing)	Adopted

Table 4 – Accelerometer characteristics and conditioner settings

Parameter	Value	Observation
Frequency limits	1 – 10,000 Hz	
Accelerometer mass	4.0 g	
Accelerometer dimensions	10 x 10 x 10 mm	
Accelerometer sensitivity	0.3178 pC/ms^{-2}	
Measurement expanded uncertainty	1.0 %	Norma EAL-R2 (U.E.)
Conditioner gain	31.6 mV/ms^{-2}	

3. RESULTS

The main results are the following. Figure 3 shows a graphic with the power spectral densities (Welch method) of the acceleration signal during the machining of VP40® steel for common and damped adaptors. According to Harris & Crede (1961), power is the work accomplishment time rate and is proportional to the harmonic vibration square amplitude. A random vibration can be considered as the sum of a large number of harmonic vibrations with different frequencies, amplitudes and phases. The total power is the sum of the power of each harmonic component of the vibration. The curves in the Figs. 3 and 4 show how this power is distributed as a function of frequency. Figure 3 contains the best result to the damped adaptor, corresponding to the 2000 rpm spindle speed and Fig. 4 shows the worst result to the damped adaptor, at 4000 rpm. The results of the other tests were intermediate.

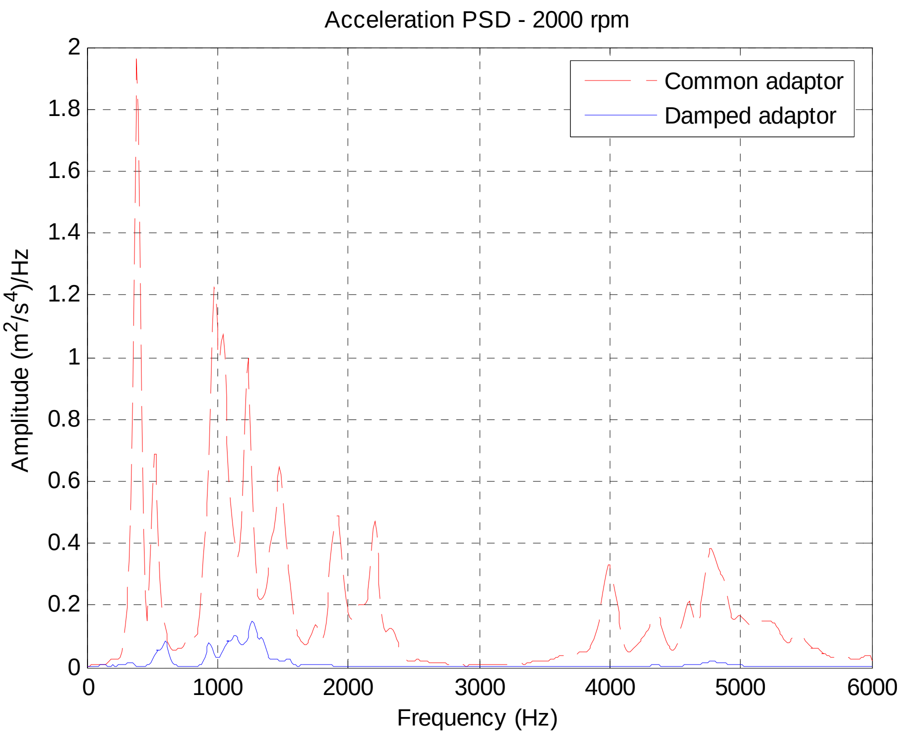

Figure 3 – Power spectral densities of the acceleration signal in down milling of VP40® steel. Spindle speed: 2000 rpm. Cut depth: 1 mm. Feedrate: 400 mm/min.

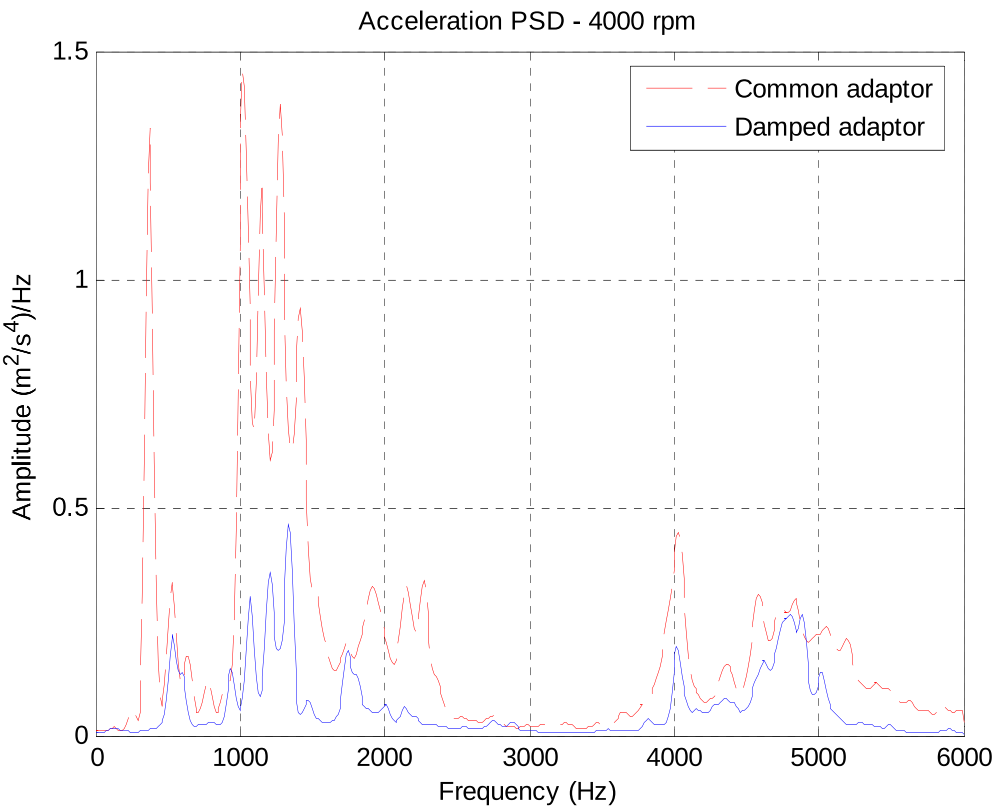

Figure 4 – Power spectral densities of the acceleration signal in down milling of VP40® steel. Spindle speed: 4000 rpm. Cut depth: 1 mm. Feedrate: 800 mm/min

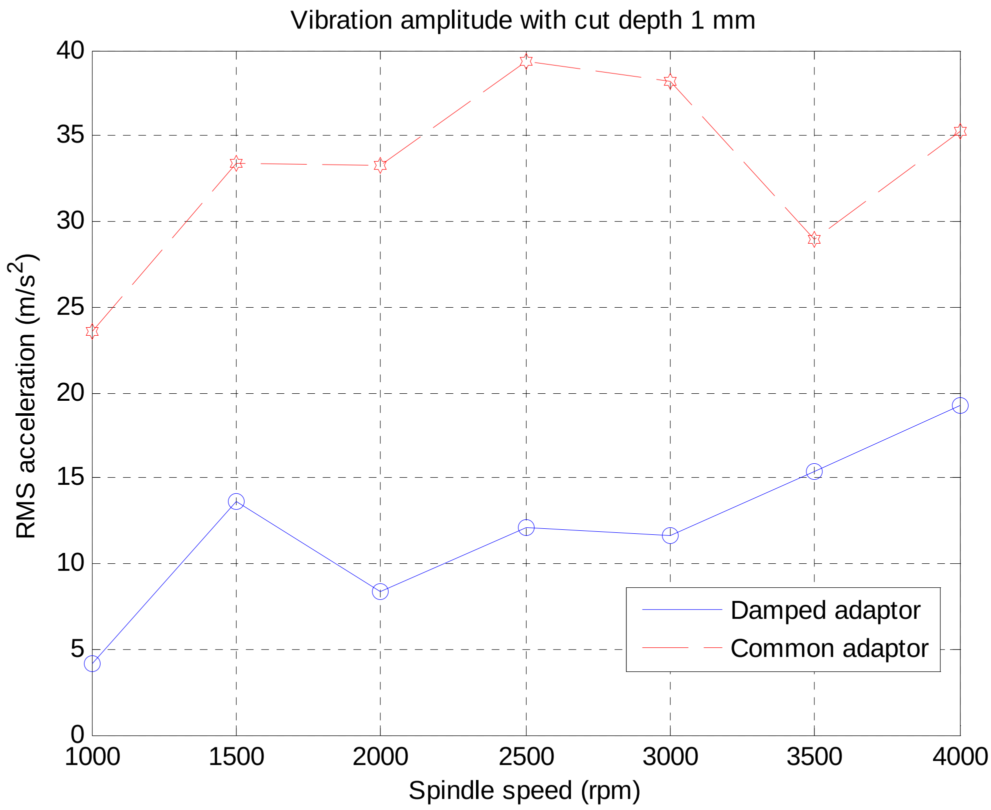

Figure 5 – Acceleration RMS level as a function of spindle rotation speed. VP40® steel down milling. Cut depth: 1 mm.

Figures 5 and 6 show the acceleration RMS levels for down milling of VP40® steel, measured at the spindle main bearing of the machining centre, using 1 and 2 mm cut depth, respectively. The comparison shows a clear advantage to the damped adaptor at all spindle rotation speed. Figure 6 also reveals a drop in the damped adaptor performance with the increase of speed.

Figure 7 shows the rugosity parameter R_a as a function of the tool rotation speed for roughing with cut depth 1 mm. The tests were performed with the same cutting conditions for both adaptors. Now, the radial immersion is 25 mm (inserts holder diameter). It can be observed the advantage of the damped adaptor at all tests.

Figure 8 shows the acceleration RMS level in down milling of the VP40® steel, in finishing conditions, with a small 0.3 mm cut depth. The common adaptor had vibration level reduction with the increase of speed and the damped adaptor had opposite behaviour. Figure 9 shows the rugosity parameter R_a as a function of rotation speed for the down milling of the VP40® in finishing conditions.

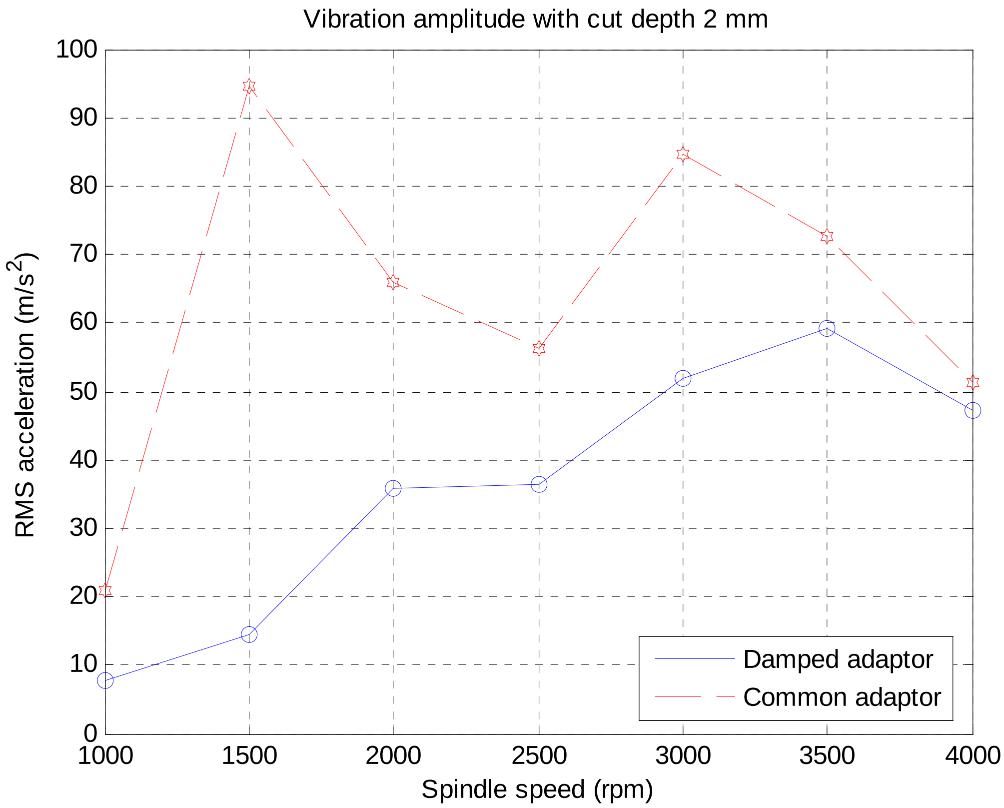

Figure 6 – Acceleration RMS level as a function of spindle rotation speed. VP40® steel down milling. Cut depth: 2 mm.

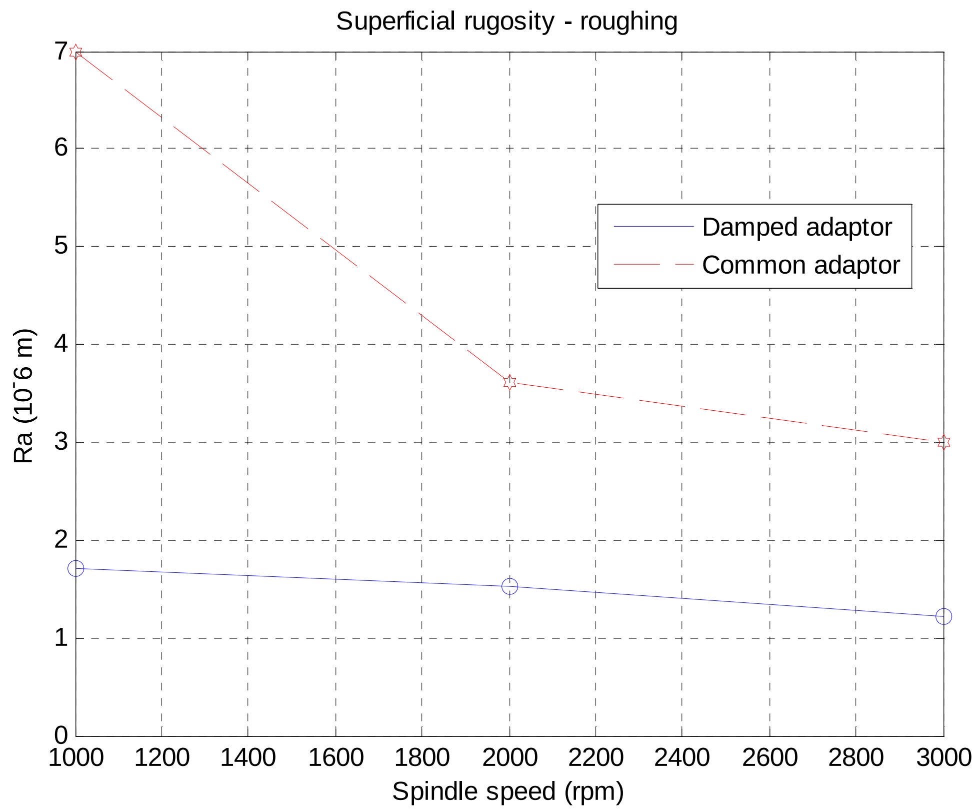

Figure 7 – Rugosity (Ra) after roughing. Cut depth 1 mm. Full radial immersion (25 mm).

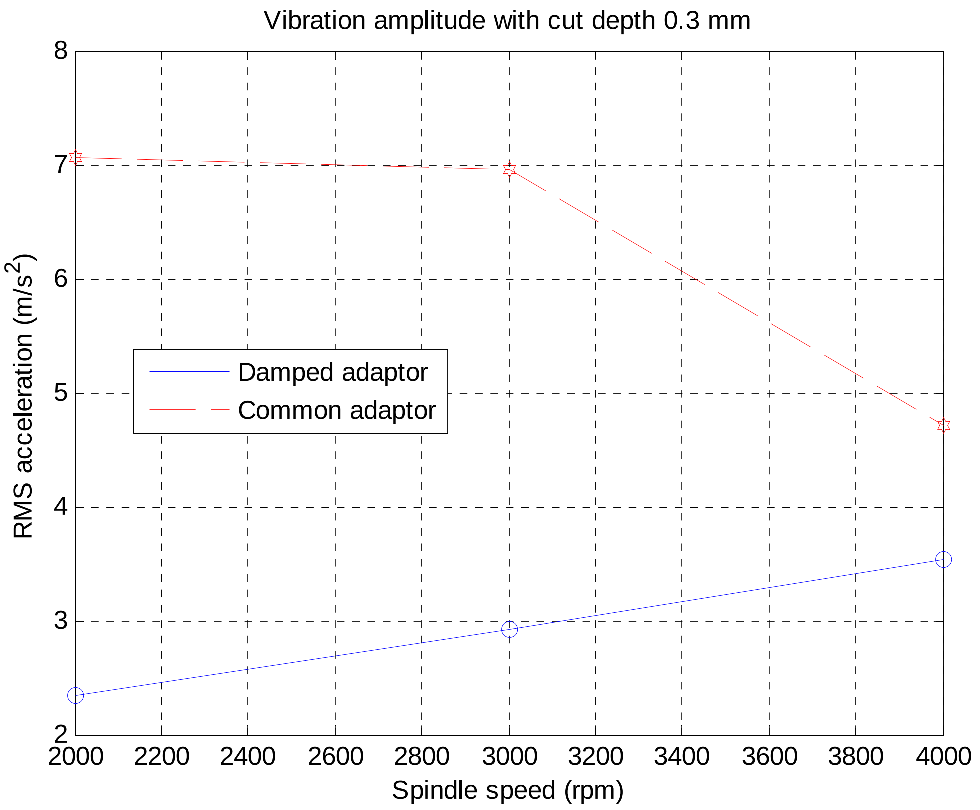

Figure 8 – RMS acceleration in VP40® steel down milling. Cut depth 0.3 mm.

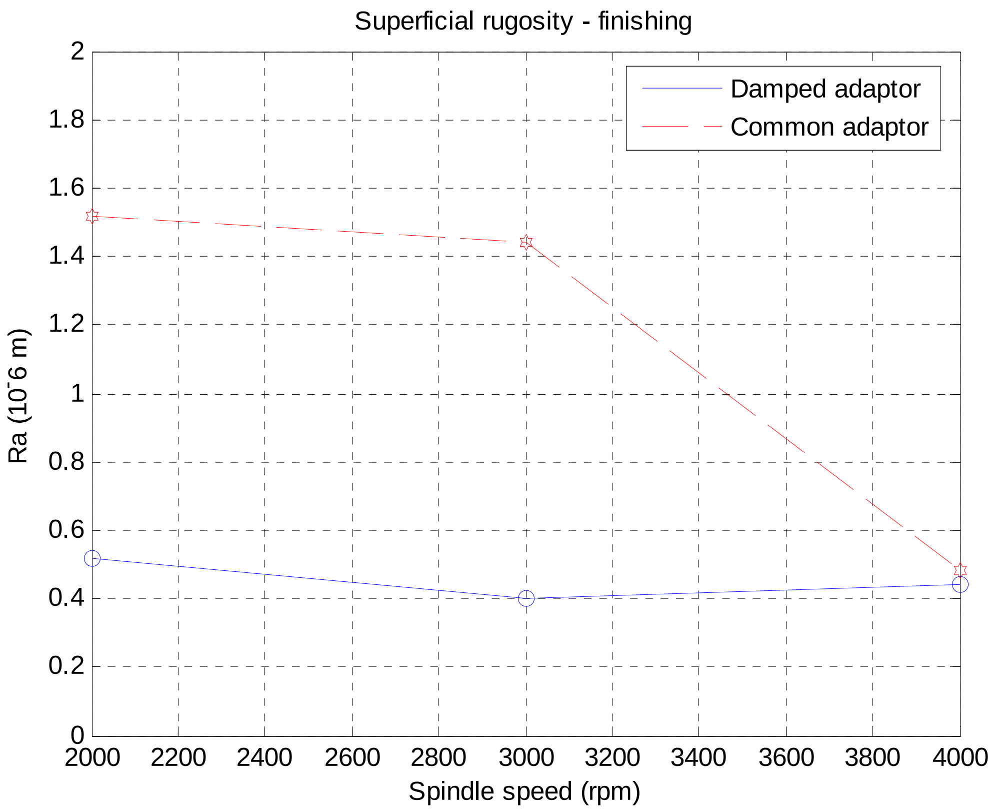

Figure 9 – Rugosity (Ra) after finishing. Cut depth 0.3 mm. Full radial immersion: 25 mm.

4. DISCUSSION

The vibration was measured in the milling machine X-axis positive direction, with the accelerometer positioned on the main spindle bearing. At this position, there is also vibration from spindle roller bearings. As the objective is to evaluate the vibration transmission from cutting tool to the milling machine, it was a good choice. If one wants to relate vibration and machined part superficial rugosity, the accelerometer should be positioned on the part, measuring at the vertical direction.

At all the tests, there was a considerable reduction of the vibration levels when using the damped tool. The tool internal damping system transforms part of the vibration energy in heat. The acceleration signal power reduction is clearly shown by the curves in Figs. 3 and 4. It must be observed that this reduction happened in a large bandwidth, from zero to 6000 Hz. There was a higher heating of the damped tool, but the temperature was not measured, because a thermometer was not available.

As expected from the vibration passive dampers theory, the tool internal damping system performance is not the same for all spindle rotation speed. There was higher efficiency under 3000 rpm. To higher speeds, there is an efficiency loss and the resulting acceleration level and superficial rugosity approximate those of the common adaptor. Figure 5 shows a 75% reduction of the acceleration RMS level in the range from 2000 to 3000 rpm, when using the damped adaptor, which is an excellent result considering it is a vibration passive damper.

The relation between vibration level during the cut and the machined surface rugosity is not always linear and direct, as can be observed by comparison of Figs. 8 and 9. For the common adaptor, the vibration level reduction with the rotation speed resulted in a proportional superficial rugosity reduction, as expected. Nevertheless, the damped adaptor presented a small increase in the vibration level with increasing speed, resulting in an almost constant low surface rugosity level, which is a positive aspect. Figure 9 reveals that the resulting superficial rugosity equalizes for both adaptors at 4000 rpm. The dynamic interaction between the adaptors and the machine tool causes these behaviour differences. It is a complex phenomenon and is beyond the purpose of this article. More details can be found in Smith & Tlusty (1990) and Insperger et al. (2002).

5. CONCLUSION

The mould and die deep cavity milling is a difficult operation due to the high length / diameter ratio of the adaptor, associated with the material high hardness. The dynamic system composed by the milling machine, work-piece and adaptor is complex and its dynamic behaviour is influenced by the Z-axis vertical position and also by the XY machine tool table position.

The damped adaptor adds damping to this system, transforming part of the vibration energy in heat. It was experimentally evaluated by direct comparison with a common adaptor with the same external dimensions and aspect, but with close (not identical) mass and stiffness. This fact doesn't invalidate the comparison, but disturbs it. The same inserts were used in both adaptors. The damped adaptor had superior results at all the tests, with the better performance in the range between 2000 to 3000 rpm, when a 75% RMS acceleration reduction was observed at the machine spindle bearing. This certainly will increase its durability, keeping its spin precision for a long time. The machined part superficial rugosity was reduced up to 66% in the 2000 to 3000 rpm range, with 0.3 mm cut depth. This is very important in the mould and die manufacturing, due to the minimal superficial rugosity requirement in this application. Moreover, in the 21 tests with the damped adaptor, there was not insert breakage, whereas at the same tests with the common adaptor, this happened three times. It was concluded that the damped adaptor is efficacious, reduces vibration, improves the machined part superficial finishing, reduces inserts expense and increases machine tool life.

6. ACKNOWLEDGEMENTS

The authors express gratitude to the Engineers Aldeci Santos and Francisco Marcondes for technical support and loan of the common and damped adaptors. The authors also thank Prof. Dr. Álisson Rocha Machado for his valuable comments and suggestions. The authors also thank state agency FAPEMIG for the acquisition of the indispensable equipment to the accomplishment of this work (project TEC930/2003). The first author thanks CNPq for the financial support.

7. REFERENCES

Harris, C.M. & Crede, C.E., 1961, "Shock and Vibration Handbook", vol. 1, cap.11: Statistical Concepts in Vibration, by Miles, J.W. & Thomson, W.T., p. 5-7, ed. McGraw-Hill, New York, USA.

Insperger, T. et al., 2002, "Stability of up-milling and down-milling, part I: alternative analytical methods", Int Jou of Mach Tools & Manufac, v. 43, p. 25-34.

Pinedo, C. E., 2004, "Nitretação por plasma proporciona endurecimento superficial de aços-ferramenta", Plástico Industrial, p.172 – 179, abril.

Resende, M.F.C & Gomes, J.O., 2004, "Competitividade e potencial de crescimento do cluster de produtores de moldes para a indústria do plástico de Joinville", Revista Nova Economia, Belo Horizonte, MG, 14 (1), 67-104, janeiro-abril de 2004.

Smith, S. & Tlusty, J., 1990, "Update on High-Speed Milling Dynamics", ASME Jou Eng for Ind, v. 112, p. 142-149.

Vallejos, R. V.& Gomes, J. O., 1998, "Uma reflexão sobre as ferramentarias nacionais", Revista Plásticos, São Paulo, SP, p. 96-101.

8. Responsibility notice

The authors are the only responsible for the printed material included in this paper.