CONTACT RECOGNITION BETWEEN GRINDING WHEEL AND WORKPIECE

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Abstract. In periods of economical crisis efficient processes become specially required. In the manufacturing industry the grinding process shows itself as one of the most used technologies when great quality and close tolerances are required. A commonly way to increase the performance of the grinding process consists in using the acoustic emission signal of the grinding process to enhance and to control the process. Among several applications of the acusting emission signals, the recognition of the contact between grinding wheel and workpice in order to define a reference position to start the job is highlighted in this paper. The paper describes a procedure to detected the contact and simultaneusly stores the infeed position of the grinding wheel for future use. Two acoustic emission monitoring systems (MS) were used separately in order to compare their efficiency in recognizing the contact between grinding wheel and workpiece. The marks obtained on the specimen during the experiments were measured and used as input data on a Factorial Analyis which has led to an optimized condiction for both MS. The AE_{RMS} signals from the events of contact have been analysed to extract useful information.

Keywords*: Grinding, Process monitoring, Acoustic emission*

1.INTRODUTION

Nowadays, the high competition between companies that work on manufacturing process urges for the development of intelligent solutions to reduce costs and time-spending operations. New strategies need to be implemented toward the reliable productivity and at the same time to the customer satisfaction. Among the current process, grinding presents itself as one the most used process on daily manufacturing activities, being used usually to produce parts with good surface quality and close tolerances. As grinding is generally situated at the end of the production chain unexpected mistakes have to be avoided, otherwise it can result on increasing production costs and even wasted parts.

A commonly way to satisfy such needs consists in using monitoring systems to improve the grinding process. In practical applications the acoustic emission (AE) signals of the grinding process have been used since the end of the eighties (Kluft, 1989) as a possible way to monitor the grinding process. Besides the possibility to control the process behavior it is also feasible to identify the exact moment of contact between grinding wheel and workpiece (Leme, 1999). A reference position can be determined when contact is detected trough the AE signal, serving as a starting point to the following grinding operations. On conventional grinding applications, this reference point is obtained through plunge grinding until the contact between grinding wheel and workpiece is recognized by spark visualization. The physical contact mark (impression) must be as small as possible in order to cause no significant changes in the dimensional characteristics of the workpiece.

In the present work, the recognition of the contact is realized integrating a monitoring system with an AE transducer into the NC command of the machine tool. To allow the observation of the AE_{RMS} signal in real time, the monitoring system is connected to a laptop. The AE_{RMS} signals depend on the grinding speed v_s, the infeed velocity of the grinding wheel v_{fr}, the constant time of the AE_{RMS} signal and the type of trasnsducer used. During the experiments the signals of the contact have been recorded and sampled aiming an additional analysis. The contact of the grinding wheel with the workpiece generates a contact mark on the workpiece. The depths of the marks were measured after the contact experiments in order to use them as input data in a Factorial Analysis. The Factorial Analysis has led to the determination of an optimized condition to the recognition of contact after varying the 3 factors in 2 different levels.

2. STATE OF THE ART OF AE IN GRINDING

When a material is deformed by some kind of external stimulus, as occurs on grinding operations (contact and friction between grits and workpiece) the lattice structure of the material is distorted and rearranged. This process provides enough energy to generate tension waves (Rayleigh waves) on layers situated near the origin. This waves travel in a solid, liquid and gas and can be detected by a suitable transducer and are called “acoustic emission” (AE) (König, 1990). The propagation velocity of the waves is a function of the density and the modulus of elasticity of the medium in which the wave is propagating ($v^2 = E/\rho$)**.**The bigger the modulus of elasticity of the material, the higher will be the propagation speed of the wave. On the other side, the higher the density of a medium, the smaller will be the velocity of the wave inside this medium. (Sena, 2007). The waves diffuse inside the solid mediums as volumetric waves. Their amplitudes (A) are related to the distance (r) as shown in Eq. (1), (Margot, 2005).

$$A \approx \frac{1}{r} \tag{1}$$

2.1. SOURCES OF ACOUSTIC EMISSION ON GRINDING PROCESS

The grinding process is characterized by the simultaneous contact of a large amount of cutting edges on the surface of the workpiece. All the individual contacts that are caused by the grits can be considered as a source of pulse deformation or stress on the workpiece. During the grinding process, as the grains wear increases with time, the individual characteristics also change, leading to different cutting edges and grains distributions on the grinding wheel. Therefore, many distinct causes must be considered as possible sources of acoustic emission on grinding process, Fig.1. The isolated pulses that are generated on this process can be considered as a result of the grain penetration on the workpiece and the wear and crack behavior of the grains, as well as bonding material behavior. Another fact that contributes to the acoustic emission consists in the changes of the microstructure caused by thermal loads in the interface of contact between grinding wheel and workpiece. (Karpuschewski, 2001)

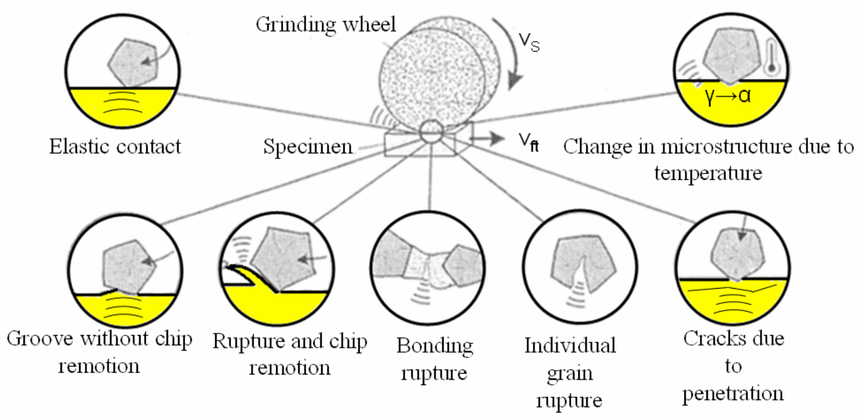


Figure 1. Sources of acoustic emission in the interface of contact between grinding wheel and workpiece (Karpuschewski, 2001).

2.2. ACOUSTIC EMISSION SIGNALS ON GRINDING PROCESSES

The raw acoustic emission signal is fulfilled with different high frequencies on different energy levels and is difficult to interpret. One of the most employed techniques to extract useful information from the RAW acoustic emission signals (AE_{RAW}) consists in the use of the RMS value (root mean square) of the acoustic emission signals "Hwang et al.(2000)". The AE_{RMS} represents a physical dimension of the AE signal intensity and depends directly from the amount and dispersion of stress on the material (Meyen, 1991). According to "Hwang et al.(2000)", the AE_{RMS} signal is defined as:

$$AE_{RMS} = \left[\frac{1}{\Delta T} \int_0^{\Delta T} V^2(t)dt \right]^{1/2} \tag{2}$$

Where:
V= RAW acoustic emission signal (AE_{RAW})
ΔT= Integration time constant

The AE_{RMS} (rectified value of AE signal) has been successfully used to monitor several grinding situations however, the spectrum analysis can complement the interpretation in situations where the RMS technique cannot allow satisfactory results (Gomes, 2001)

2.3. ACOUSTIC EMISSION SIGNALS DURING THE CONTACT BETWEEN GRINDING WHEEL AND WORKPIECE

The contact recognition between the grinding wheel and the workpiece depends on the transducer, the amplifier and the processing procedure of the signal. This leads to a time delay and first physical contact of grits and workpiece may happen before any appreciable change in the signal, especially with RMS signals. The contact is usually judged according to a significant change of the amplitude of the AE_{RMS} signal, or the AE_{RAW}. Therefore, understanding the instantaneous features of wheel/workpiece interaction may help to define "contact" for performing efficient use of the AE_{RMS} signal (Leme, 1999). Theoretically, each cutting grit generates a burst type of AE signal when it cuts through the workpiece. When numerous grits cut though the workpiece in such a way that the interval of two consecutive cuts (which are not necessarily in the same place) is much shorter than the decay time of each burst signal, then a continuous type AE is formed. "Webster *et al.* (1996)". The continuous AE signals generated when many grains on the wheel periphery simultaneously touch the surface of the workpiece can be represented by diverse parameters, Fig.2. (Asher, 1997); "Akbari et al. (1996)" (Fingerle, 2008)

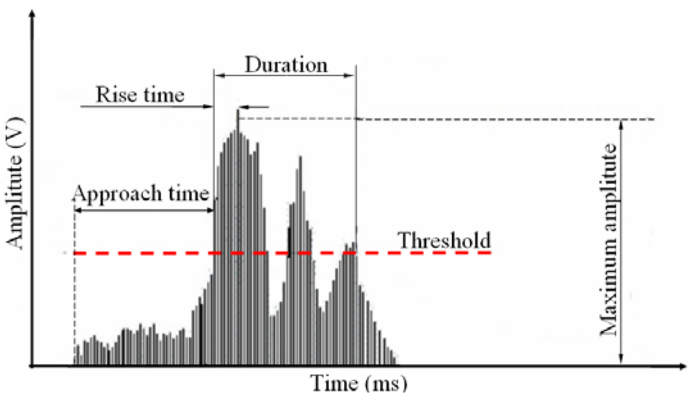


Figure 2. Characteristics parameters on AE signal. (Asher, 1997)

2.4. BINARY AE DETECTION BY USING AE$_{RMS}$ SIGNALS

The binary technique by using the AE$_{RMS}$ signals consists in one of the most common and simple way to recognize the first contact between grinding wheel and workpiece (or dressing wheel and dressing tool) on the grinding process. In this technique lower values of a threshold are generally used combined with higher values of gain (amplitude) and lower values of the constant time, ΔT. (Treis, 2007), (Oliveira)

Through the precise contact recognition between grinding wheel and workpiece (or between grinding wheel and dressing tool) many distinct applications can be implemented, for example, anti-collision systems, spark-out control, grinding wheel automatic preset (measuring the wheel with a diamond probe) workpiece dimensional measuring before grinding (to monitor the previous machine operation) and touch dressing contact detection. (Oliveira)

The first feature that can be extracted from the AE signal showed in the Fig. 2, consists in its "approach time". This parameter can be defined as the time interval between the start of the signal until the instant in which it oversteps the previously defined threshold. The "rise time" is the next attribute and lasts from the first overstepping of the threshold to the point of time when the maximum amplitude occurs. Approach time and rise time together make up the time between the first overstepping of the threshold and the appearance of the maximum amplitude. Another characteristic which may be observed from Fig.2 is the signal duration. It is defined as the time between the first and the last overstepping of the threshold. The last useful parameter to be considered is the "maximum amplitude" which corresponds to the point on the signal curve with the biggest value in terms of AE$_{RMS}$ "Ravindra *et al.* (1997)"; (Asher, 1997)

After a safe recognition of the contact between grinding wheel and workpiece the signal is ready for a further use. A signal lamp can sign to the operator to stop the infeed motion of the grinding wheel or this signal can be used directly by the CNC of the grinding machine for the same purpose. In any of these procedures a time will pass and the minimal depth of the mark on the workpiece will depend of the sum of the time of the monitoring system and the reaction time of the CNC

3. EXPERIMENTAL SETUP

The experimental setup has been designed for the recognition of contact experiments to be performed in a cylindrical CNC grinding machine (Zselics Pratika Flexa 600-L) as schematically represented on Fig. 3. Two equivalent AE monitoring systems were used separately. The AE signals related to the event of contact were achieved by employing piezoelectric AE transducers with direct transmission. These transducers, delivered by the manufacturers of the AE monitoring systems (MS), have been installed at an appropriate place on the machine. The chosen position on the tailstock showed the lowest interference from the moving components on the machine, but a good signal from the process. The AE transducer from each manufacturer has been used, each for the specific monitoring system. The AE$_{RAW}$ signal from the transducer is transmitted to the monitoring systems through appropriate cables delivered by the MS manufactures. Both MS carry out a signal treatment in order to convert the AE$_{RAW}$ signal into AE$_{RMS}$ signal. When the A MS (Dittel, 2007) was used the AE$_{RMS}$ signals were sent directly to a laptop by a RS-232 interface and could be visualized on the monitor of the laptop by the aid of the specific software which accompanies this MS. This software permits to digitalize the AE$_{RAW}$ signal using a sampling rate of 1000 Samples/s. When the B MS was used (Sensis, 2002) the AE$_{RMS}$ signals assigned to its analog output were sent to a multi-analyzer system (Oros, 2006) through coaxial cables. The multi-analyzer was also connected to a laptop, then allowing the visualization, storage and sampling of the AE signals aiming at a pos-analysis. During the experiments a sampling rate of 2048 Samples/s has been chosen by means of the software (Oros, 2006). The use of a multi-analyzer was necessary because the B MS does not have any specific software to visualize the AE signals from the event of contact between grinding wheel-specimen.

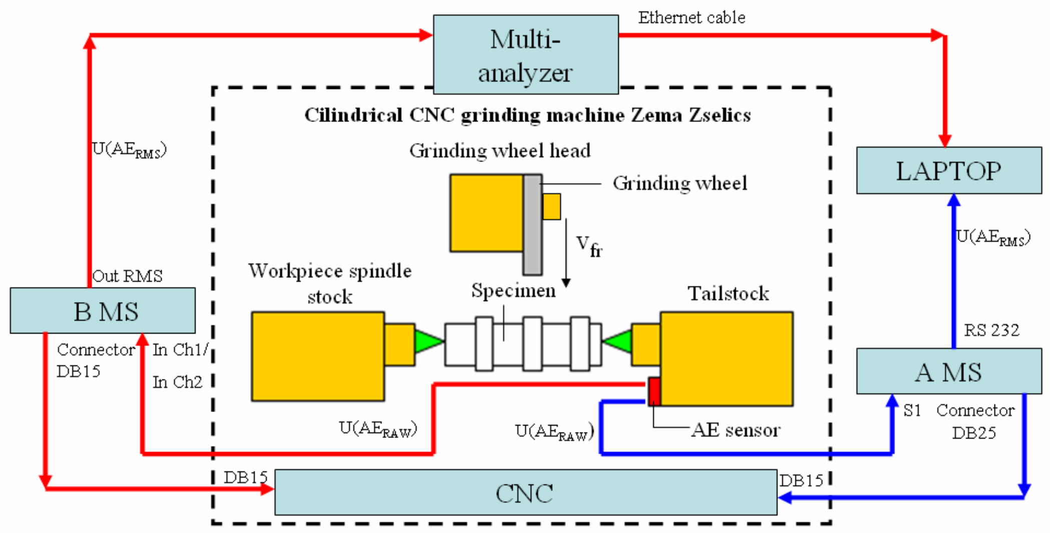


Figure 3. Experimental set up during tests to the recognition of contact between grinding wheel and workpiece.

The A and B MS were connected to the CNC command of the grinding machine by means of a DB-15 connector installed into the CNC command of the machine. As the AE_{RMS} signal (from the contact) exceeds the AE-Limit 1 (threshold) previously adjusted by the user of the MS an voltage signal is delivered to a specific input in the CNC command which acts on the stopping of the infeed motion of the grinding wheel, v_{fr2}

4. EXPERIMENTAL PROCEDURE

The experiments were developed by plunge grinding with a CBN grinding wheel against the surface of the ABNT 1040 steel specimen. During the contact experiments the specimen was kept static (v_w= 0 m/s). All the tests aiming at the recognition of contact between grinding wheel and specimen were developed without cutting fluid. The cutting speed of the grinding wheel was maintained constant along the experiments, and equal to v_s= 22.5 m/s.

Before starting the experiments the grinding wheel was dressed and the transducers and MS installed. Due to the fact, that the amount of material removed on each contact experiment is very small and the specific removal rate Q'_W, is also very small during the experiments, the wear of the super abrasive grinding wheel can be considered negligible during the experiments. The specimen was fixed between the tailstock and the headstock of the machine being positioned orthogonally to the infeed direction of the grinding wheel, as illustrated on Fig. 4-a. At the beginning of each experiment the grinding wheel has been positioned 250 mm from the specimen (X^+= 250) and was set to be used with a wheel speed of v_s= 22.5 m/s. Figure 4-b shows briefly all the stages of movement described by the grinding wheel during the experiments. The grinding wheel was guided toward the specimen in a plunge operation using an infeed velocity, v_{fr1}= 6000 mm/min, until a specific position situated at 0,5 mm away from the specimen (point 1 on Fig. 4-b). Thereafter, the infeed velocity was changed to the approximation speed v_{fr2}, until the contact could be recognized by the AE monitoring system (point 2 on Fig. 4-b) and stopped and reversed (point 3 on Fig. 4-b) by the CNC of the grinding machine. The displacement described by the grinding wheel from point 2 to point 3 defines the depth of the mark a_p, on the surface of the specimen.

The contact between grinding wheel and the specimen is featured by a physical mark which results from the removal of the material on the surface of the specimen during the time initiated at the first contact between a grit and the workpiece until the complete stop of the infeed motion of the grinding wheel. It is always desirable to achieve the smallest mark as possible, in such a way that the dimensional tolerances are not affected. As the level of the AE signals depends on many factors, like the infeed velocity of the grinding wheel $v_{fr,}$ the integration time constant ΔT of the RMS signal and the type of sensor used (magnetic base or threaded base), an AE monitoring system controls the experiment. These variables have been varied to produce marks on the workpiece. The depths of the marks were afterwards measured and their values have been used in a Factorial Analysis to determining an optimized condition to the recognition of contact. The two AE systems were employed separately.

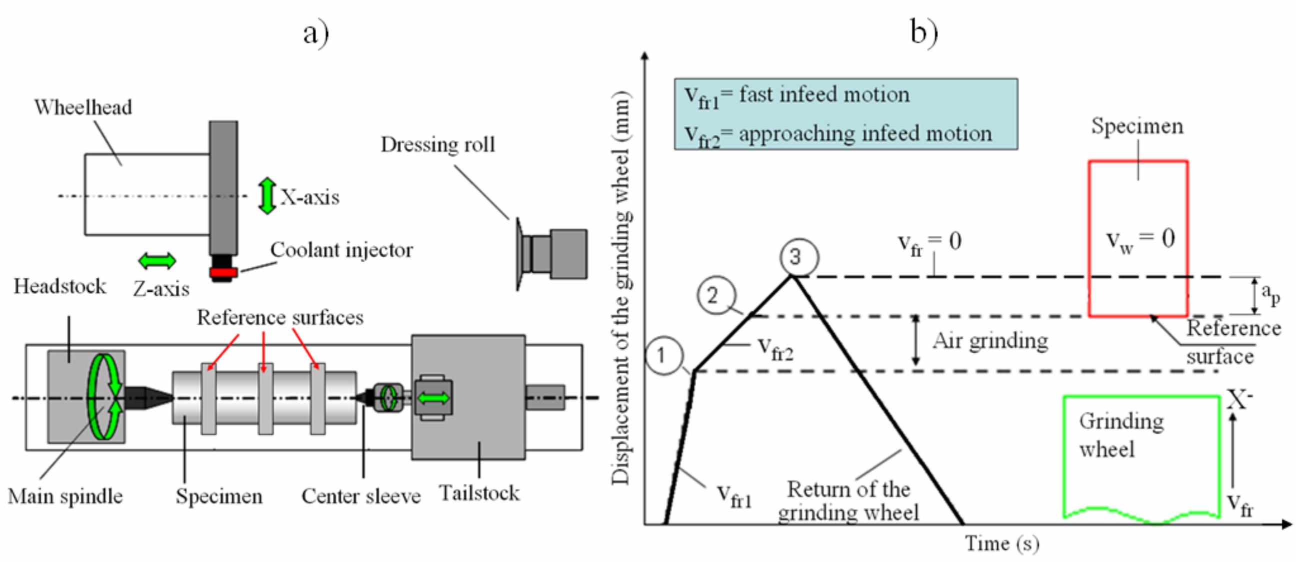


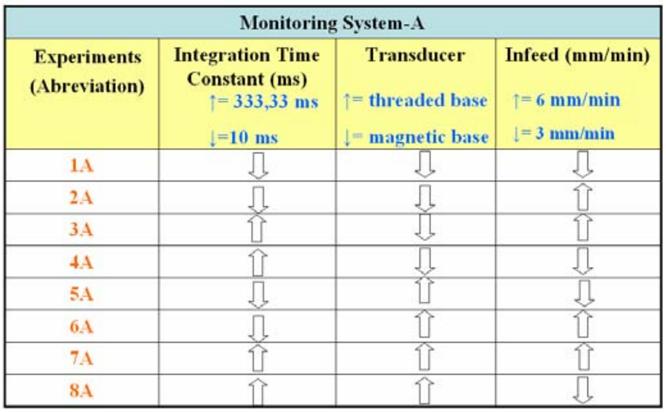
Figure 4. a- Working chamber of the grinding machine. b- Infeed motions of the grinding wheel during the tests.

After the recognition of contact and the stoppage of the infeed motion, the grinding wheel is moved away until reach a secure distance. The specimen is then turned by approximately 15º allowing the next experiment.

5. STRUCTURE OF THE EXPERIMENTS

The experiments were conducted based on the scope of a Factorial Analysis involving the 3 major factors which present influence on the first contact AE_{RMS} signals. Among these factors were considered the infeed velocity v_{fr2}, the integration time constant ΔT, and the type of sensor used. The 3 factors were then varied in 2 levels (high ↑, and low ↓) whose magnitudes were previously defined. The amount of factors and their respective levels of variation led to a total of 8 possible combinations of experiments, for each MS, as showed on Tab.1.

Table 1. Combinations of the factors and their respective levels of variation for the first contact experiments.



Monitoring System-A			
Experiments (Abreviation)	Integration Time Constant (ms) ↑= 333,33 ms ↓=10 ms	Transducer ↑= threaded base ↓= magnetic base	Infeed (mm/min) ↑= 6 mm/min ↓= 3 mm/min
1A	⇩	⇩	⇩
2A	⇩	⇩	⇧
3A	⇧	⇩	⇧
4A	⇧	⇩	⇩
5A	⇩	⇧	⇩
6A	⇩	⇧	⇧
7A	⇧	⇧	⇧
8A	⇧	⇧	⇩

The line 1A illustrates the experimental situation in which the factors "Integration time constant", ΔT (10ms), the factor "transducer" (magnetic sensor) and the factor "infeed" (3 mm/min) are set at the lower level. On the used abbreviation, the number 1 means the first combination between factors and levels, whereas letter "A" means that the A MS was used (instead of B MS). Each experimental situation was repeated 6 times, leading to a total of 48 experiments for the each MS.

When using the B MS the same methodology has been implemented. The difference consisted only in the higher value (↑) for the parameter "Integration time constant" ΔT, which assumed the value of 400 ms. Along the experiments the sensibility of both MS had to be adjusted every time the factor "Integration time constant" ΔT, or the factor "sensor" was changed to guarantee the recognition of the contact. These adjustments were necessary because both factors influenced directly the behavior of the AE_{RMS} signals on the event of contact, changing the sensibility of the MS as they led to the alteration of the AE parameters (for example: gain, noise reduction) to be selected in each MS.

6. MEASURMENT OF THE MARKS ON THE SPECIMEN

The depth of the marks generated during the contact between grinding wheel and specimen were used to verify the effectiveness of the monitoring system. The values of the depth of the marks have been used as input data on a Factorial Analysis which permitted an optimization of the use of both AE monitoring systems in recognizing the contact between grinding wheel and specimen. The marks were measured at the laboratory Laboratório de Metrologia Dimensional (LMD) of the UFSC. The measurement was carried out on a precision device (Mahr), Fig. 5-a.

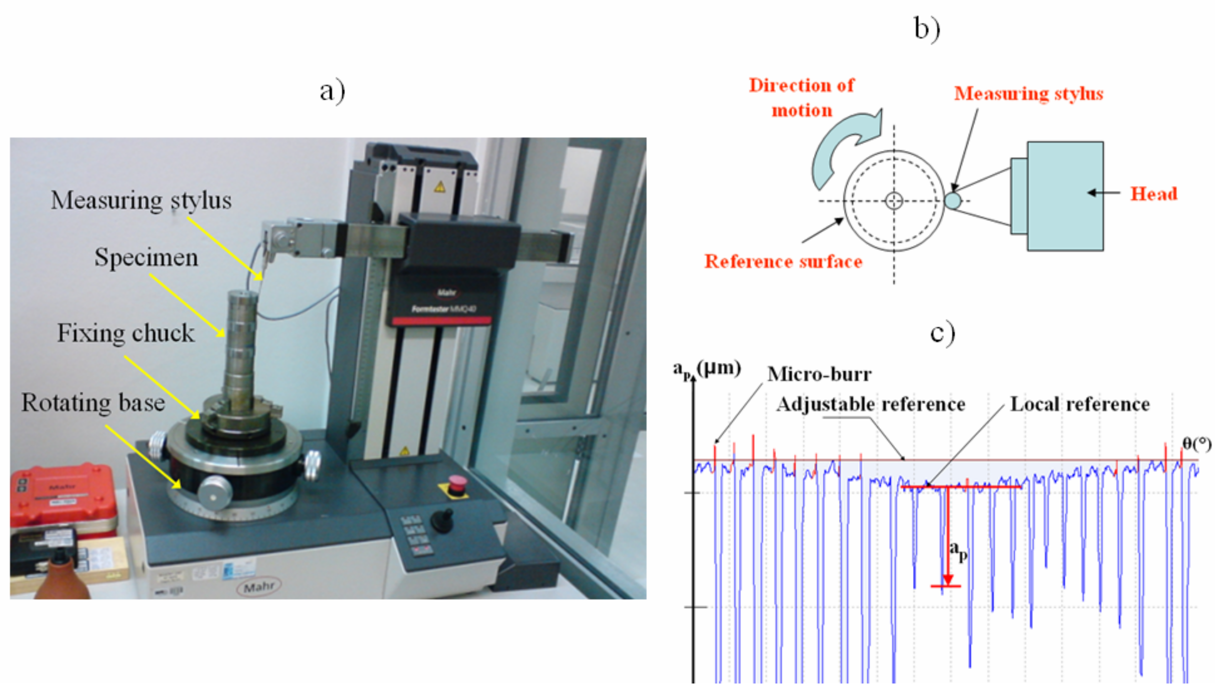


Figure 5. a- Device used to the measurement of the marks. b- Relative movement between specimen and stylus c- General aspect of the measured marks.

Along the measurements the specimen was fixed in a three jaws chuck and set to execute a complete rotation in relation to its own axis. This measuring machine uses a stylus which presents a ruby spherical tip of 1,5 mm in diameter (See Fig**.** 5-b). The stylus stays fixed during the measurement and presents only an angular displacement which is proportionally converted into a electrical signal. This signal is afterward treated and the contour of the measured surface is determined with a micrometer resolution. The contour is registered in an angular interval of 0,1°. The depth of each mark is characterized by the linear distance between an adjustable curve on the reference surface (adjusted by the software with the MMC method) and the most distant point situated on the contour. Due to the roundness deviation (about 1µm presented by the ground references surfaces) the depths of the marks were measured as the linear distance between a local reference and the most distant point situated on the contour as illustrated on Fig. 5-c. The sharp pointed aspect of the marks is due to the higher level of gain used during the measurements.

7. RESULTS

Through the realization of a Factorial Analysis an optimizing condition for the recognition of contact was achieved for each MS used. This condition takes into account all the combinations between the 3 factors involved and their respective levels of variation. The input values for this analysis were the values of the depths of the marks ($a_{p,m}$) obtained by measuring the specimen. The optimized condition has been characterized by the specific combination of factors and levels that could present the smallest value of depth. Figure 6 shows the results from this analysis to both MS involved during the experiments. Y_{A}- is the average value of the depth of marks by using A MS. Y_B- is the average value of the depth of marks by using B MS.

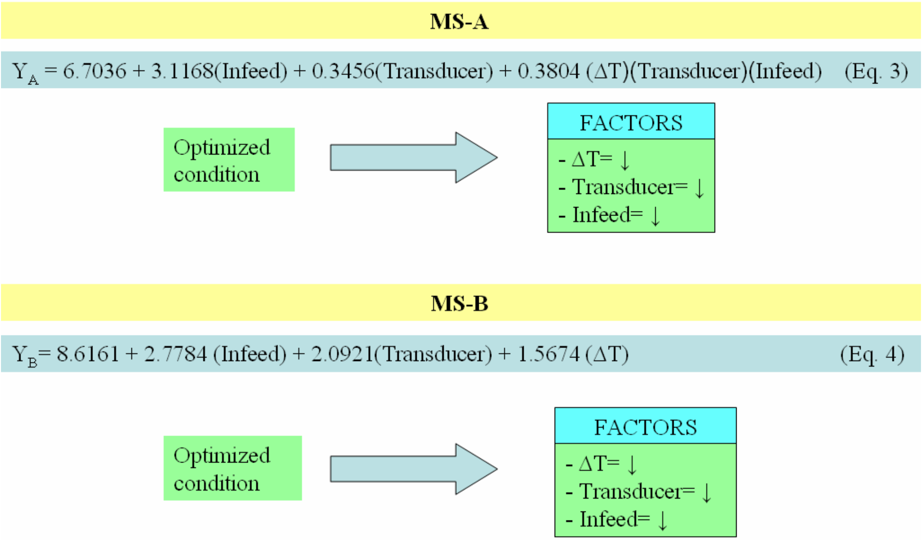


Figure 6. Optimized results for the contact recognition using both MS.

For both MS the optimized condition is a small v_{fr2}, the magnetic sensor, and low integration time. The constants values that appear at the beginning of both equation represents the mean values of $a_{p,m}$ along the 48 runs obtained for each MS during the experiments. Additionally, the coefficients that accompanies the factors refer to the effect of these parameter on the mean values of $a_{p,m.}$

Based on these results the values of the infeed speed v_{fr2}, were gradually reduced for each MS in order to carry out a comparative study regarding to the recognition of the first contact. The marks obtained in this experiment were also measured by the same way as done before. The AE_{RMS} signals were sampled and stored aiming at a pos-analysis. Table 2 illustrates the depth of the marks obtained in the experiment reducing the infeed speed.

Table 2. Depth of marks obtained after varying the infeed velocities

$a_{p,m}$ related to different values of v_{fr2}										
Infeed (mm/min)	1.5		1.0		0.5		0.3		0.1	
MS	Sensis	Dittel	Sensis	Dittel	Sensis	Dittel	Sensis	Dittel	Sensis	Dittel
$a_{p,m}$ (μm)	**0.83**	**1.77**	**0.52**	**1.31**	**0.22**	**0.44**	**0.13**	**0.22**	**0.13**	**0.09**

Despite the lower values observed in the majority of situations when using the B MS (except for v_{fr2}= 0.1 mm/min), it was not possible to affirm that this system would have a better efficiency than the A MS only by a simple comparison of these values. Aditionally, an advanced study was necessary to compare both MS. Such a study has been based on a Statistical Hypotesis Testing which considered the difference in the means of the depths obtained by using the optimized situation suggested earlier. (See Eq.3 and Eq.4). This test starts with two initial hypotheses (H0 and H1). The hypothesis H0 considers that the difference in the means is zero, (that is, H0:μ_A-μ_B = 0) and the hypothesis H1, considers that the difference in means verified during the tests should represent a better efficiency by the B MS (that is, H1: μ_A-μ_B > 0) conducting to small values of the marks on the specimen after recognizing the contact. Along the evaluations a level of significance of α= 0,05 was used. Figure 7 shows the major statistical parameters which have been calculated to achieve the conclusion about the efficiency available for both MS.

According to (Montgomery, 2001), as T_0> $t_{0,05;12}$ then the hypothesis H0 (H0: μ_A-μ_B =0) must be rejected and the hypothesis H1 can be accepted. Based on this results it is possible to conclude that the observed difference on the mean values (x_A and x_B) is representative in terms of a statistical sense. Then it can be affirmed that the B MS has presented a better efficiency in recognizing the first contact when using the optimized condition predicted by the model.

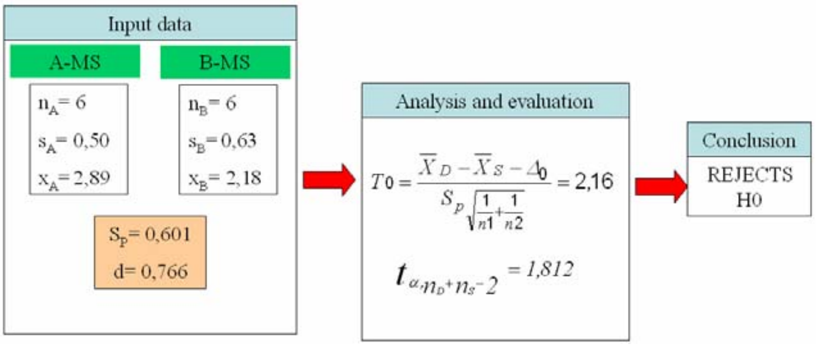


Figure 7. Statistical parameters used while evaluating the Hypothesis Test. n- Sample size. s- Standart deviation. x= mean value of $a_{p,m}$. T_0= Test statistic. d= $(x_A-x_B)/(2.S_P)$ where S_p is the estimation of the common standart deviation.

7.1. ANALYSIS OF THE AE$_{RMS}$ SIGNALS FROM THE EVENT OF CONTACT

After determining the optimized conditions for both MS the experiments were conducted in order to predict the depth of a mark employing the AE_{RMS} as a reference. For each MS, six repetitions were executed and their AE_{RMS} signals have been recorded. Figure 8 demonstrates general aspects of the first contact signals obtained for both MS.

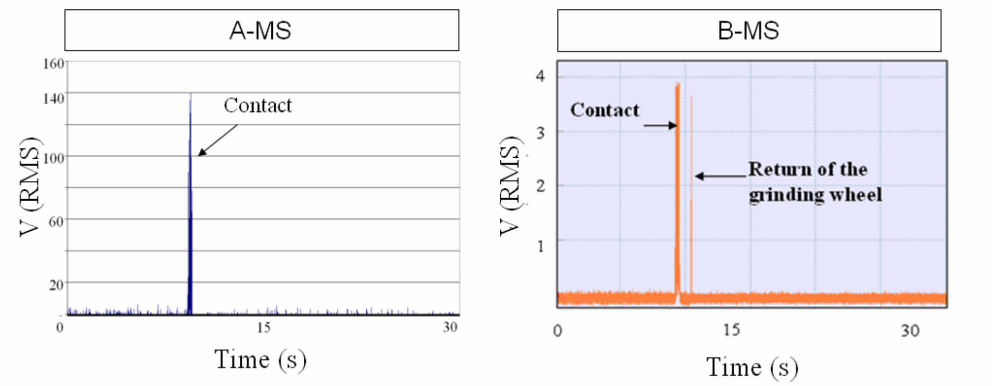


Figure 8. AE_{RMS} signals obtained on the experiments with optimized conditions.

Based on the graphics shown on Fig. 8 and by admitting that the exact moment of stoppage of the infeed motion (v_{fr2}=0) happens when the grinding wheel has penetrated a maximum depth on the specimen (which is associated to a maximum value of the AE_{RMS} signal) and by supposing that the infeed motion is always constant during the displacement of the grinding wheel it was possible to estimate the depth of the marks through the observation of the rise time $t_{R,}$ and the approaching time $t_{A,}$. Regarding to the AE_{RMS} associated to the experiments 1A1 and 1A2, the evaluation of the depth of the marks based on the AE signal ($a_{p,SIGNAL}$) has been established as follows:

Approaching time, t_A:	$t_{A,1A1}$= 4 ms	$t_{A,1A2}$= 2 ms
Rising time, t_R:	$t_{R,1A1}$= 228 ms	$t_{R,1A2}$= 236 ms
Infeed velocity, v_{fr2}:	v_{fr2}= 3 mm/min= 50 µm/s	

$$v_{fr2} = \frac{s}{t} = \frac{a_{P,SIGNAL}}{t_{SIGNAL}} \quad » \quad a_{p,SIGNAL} = t_{SIGNAL} \times v_{fr2} \qquad (5)$$

Where:

$t_{SIGNAL} = (t_R + t_A)$

Then: $t_{SIGNALl,1A1} = 4 + 228 = 332$ ms

$t_{SIGNALl,1A2} = 2 + 236 = 238$ ms

Resulting:

$(a_{p,SIGNAL})_{1A1} = 11.6$ µm

$(a_{p,SIGNAL})_{1A2} = 11.9$ µm

The same procedure has been used for the evaluations involving the other signals (1A3 to 1A6 and 1B1 to 1B6). Figure 9 displays the depth of the measured marks ($a_{p,m}$) as well as the depths of the calculated marks employing the analysis of the AE_{RMS} signal, ($a_{p,SIGNAL}$). This approach to estimate the depth of the marks has been denominated, CONSIDERATION 1.A similar approach has been used by (Fingerle, 2008), to compare the effectiveness of both grinding machines by using the A-MS. By observing the values presented in the following figure it is possible to note that the values related to $a_{p,SIGNAL}$ were considerably higher than those obtained by $a_{p,m}$, on every experimental conditions for both MS. This information makes sense as $a_{p,m}$ is directly influenced by the selected filter during the measuring of the marks.

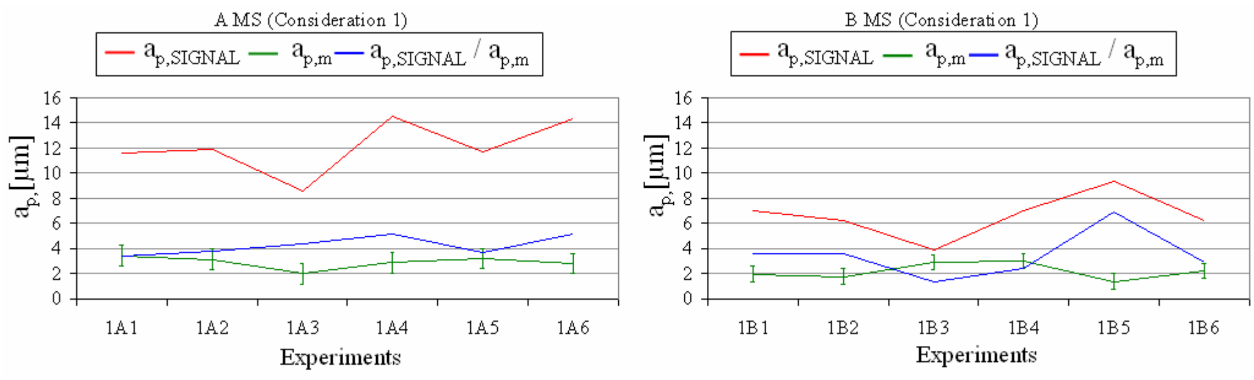


Figure 9 - Values of $a_{p,SIGNAL}$, $a_{p,m}$, and relation $a_{p,SIGNAL}/a_{p,m}$ under CONSIDERATION 1.

When the same analysis has been done to the B MS it was verified the values of $a_{p,SIGNAL}$ showed to be significantly smaller than those obtained by using the A MS. The mean values for the B MS resulted in around a depth of 6.64 µm and the relation $a_{p,SIGNAL}/a_{p,m}$ has presented a lower mean value compared to the mean value achieved by using the A MS. The results indicated a higher efficiency from the B MS in recognizing the contact, when the CONSIDERATION 1 has been employed in the evaluation of the $a_{p,SIGNAL}$

In a second approach to estimate the depth of the marks, it was considered that the stoppage of the infeed motion $v_{fr2,}$ has occurred at the instant of time associated with a level of amplitude which was immediately lower and situated before the maximum value of amplitude. This approach has been called as CONSIDERATION 2. This interpretation has led to considerably lower values of the relation $a_{p,SIGNAL}/a_{p,m}$ than that verified by the previous analysis (CONSIDERATION 1) then indicating a smaller gap existing between the $a_{p,SIGNAL}$ and $a_{p,m}$. This tendency was verified for both MS in study, as shown on Fig.10

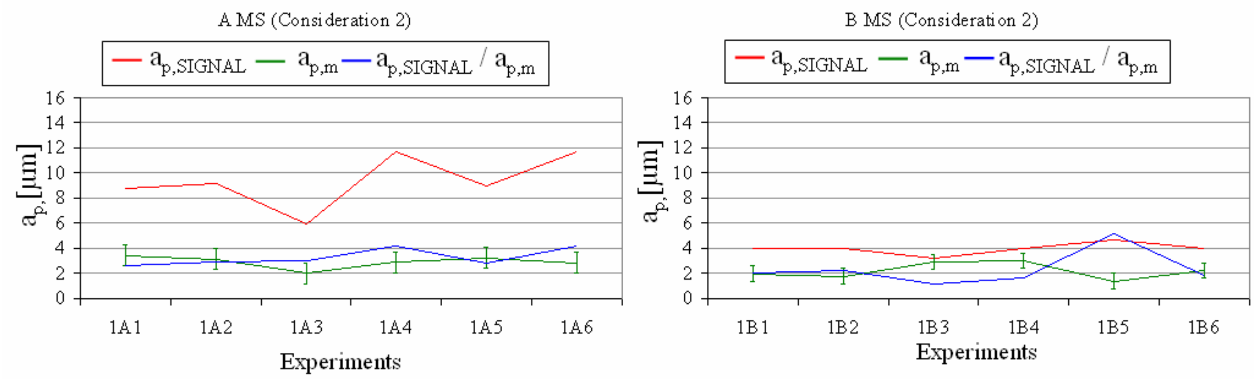


Figure 10. Values of $a_{p,SIGNAL}$, $a_{p,m}$, and relation $a_{p,SIGNAL}/a_{p,m}$ under CONSIDERATION 2.

Additionally, the analysis of $a_{p,SIGNAL}$ under the CONSIDERATION 2 has also demonstrated a better efficiency featured by the B MS resulting in average values of $a_{p,SIGNAL}$ in the order of 4.4 µm, that is, 2.1 times lower than those obtained by using the A MS. It was also seen that the variability on the values of $a_{p,SIGNAL}$ has demonstrated to be smaller when using the B MS under CONSIDERATION1 and CONSIDERATION 2.

8. CONCLUSIONS

The most important conclusions of this work are that a monitoring system based on AE is feasible to detect the first contact between grinding wheel and the specimen. The optimized results obtained from the Factorial Analysis (Eq.4 and Eq.5) shows the average values of the marks were reduced when using the A MS (x_A= 6.7 µm against x_B= 8.6 µm).The final result achieved from the Statistical Hypostesis Testing proves the B MS can be considered better than the A MS in recognizing the contact on the employed CNC grinding machine. The better efficiency presented by the B MS was also proved when comparing the average values of the depths of the marks by measuring ($a_{p,m}$) and the averages values of the depths obtained by analyzing the AE_{RMS} signals from the event of contact.

When the efficiency of both MS are compared based on the values of $a_{p,m}$, the B MS appeared to be slightly better than the A MS conducting to depths of the marks with lower values in average ($x_{A,m}$= 2.89 µm against $x_{B,m}$= 2.19 µm) than those obtained by using the A MS in the optimized condition. This tendency was also confirmed through the Hypothesis Testing described earlier.

The depths of the marks estimated through the analysis of the AE_{RMS} have been done under two considerations. In both considerations (CONSIDERATION 1 and CONSIDERATION 2) the average values of the depths were lower when using the B MS. Under the CONSIDERATION 2 the mean values of the depths obtained when using the B MS and the Dittel MS, were $x_{A,SIGNAL}$= 9.3 µm and $x_{B,SIGNAL}$= 4.4 µm, respectively. Additionally, by observing the results demonstrated on Fig. 11 the variabilility among the six repetitions (in the optimized condition) when using the B MS ($\delta_{S,SIGNAL}$= 1.39) was lower than that visualized for the A MS ($\delta_{D,SIGNAL}$= 2.16),

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10. RESPONSIBILITY NOTICE

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