T4.1.

CYLINDER BORE HONING

- 4th Reporting Period (36 to 48 month) -

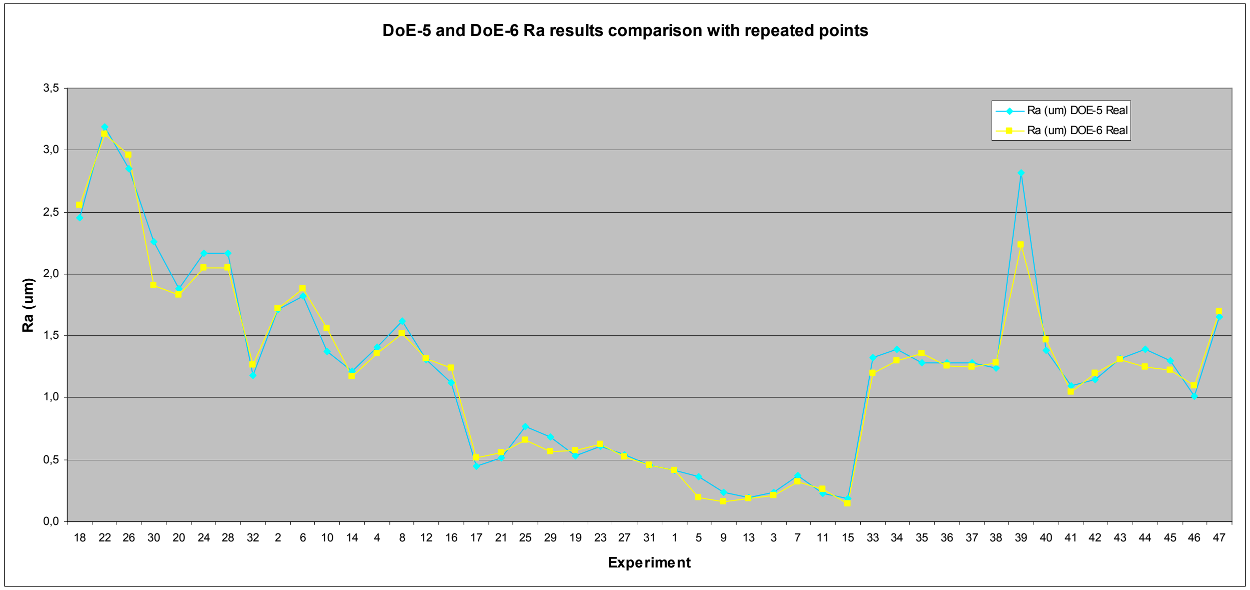
Objectives of Reporting Period:

- MATHEMATICAL HONING MODELS:
  - To obtain the definitive mathematical models for rough and semifinishing honing processes from the results of DoE's in the abrasive test machine and to adjust to machined tubes in an industrial honing machine.
  - To obtain the mathematical models for finishing honing processes.
- SEMI-ANALYTICAL PLATEAU-HONING MODEL:
  - To obtain the plateau-honing semi-analytical model and to validate it with tubes machined in an industrial honing machine.
- FUNCTIONAL BEHAVIOUR:
  - To analyze of the hydraulic cylinders tested in life cycle test benches, looking for the best functional behaviour of the cylinder surface textures.
- ULTRASONIC ASSISTED HONING:
  - To define and perform an ultrasonic assisted honing experimental test.

Research/work performed in the 4th Reporting Period:

• ***Mathematical honing models planned***:

Empirical models for honing have been done using the measures and data analysis of the last DoE's results (DoE-5 and DoE-6) for medium and large abrasive grain size, machined by Honingtec in the abrasive test honing machine.



Experimental results: Ra, Rt, Rq, Qm

Mathematical relations with quadratic terms have been found for rough and semifinishing honing processes parameters:

$$Ra, Rt, Rq, Qm = \varphi\,(Gs, TD, Vl, Vt, P)$$

$$Ra = -3.96743 - 0.00398962*Gs + 0.0773905*T + 0.0322614*Vt + 0.00179538*P + 0.000073570*Gs^2 - 0.000604828*T^2 - 0.000105318*Vt^2 - 0.0000792654*Gs*T - 0.0000217231*Gs*Vt + 0.0000117975*Gs*P - 0.0000247565*T*P$$

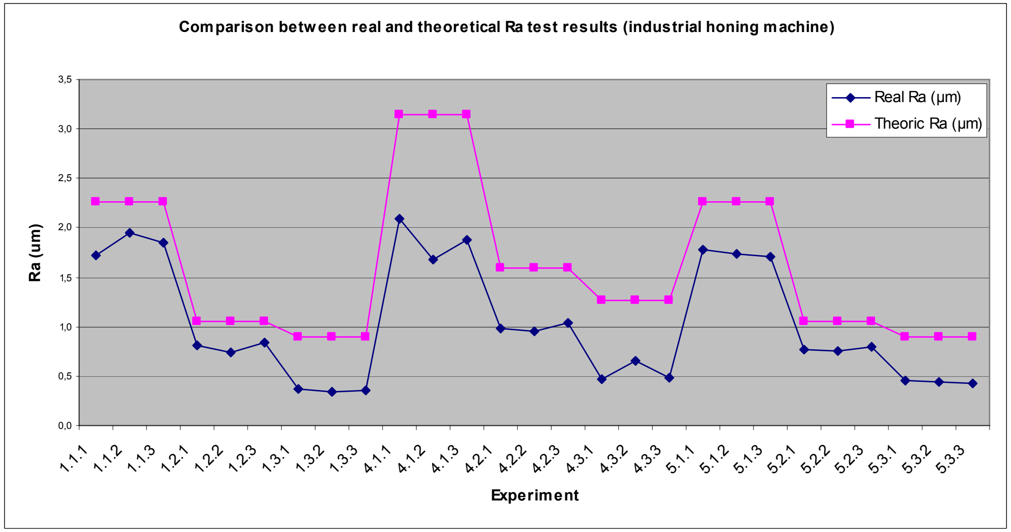
$$Rt = -37.5548 + 0.00158608*Gs - 0.00476463*T + 0.381268*Vt + 0.0742900*P + 0.000462049*Gs^2 - 0.00131505*Vt^2 - 0.000086629*P^2 - 0.000660206*Gs*T - 0.00018077*Gs*Vt + 0.000073012*Gs*P + 0.000056499*Vt*P$$

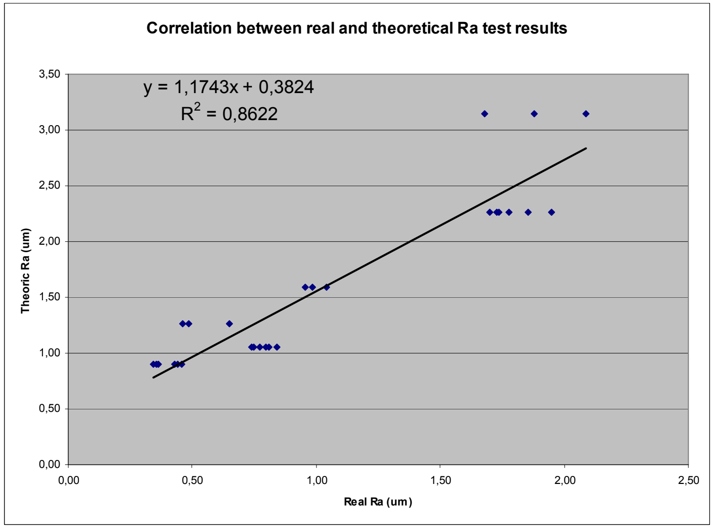
$$Rq = -8.65460 - 0.00481193*Gs + 0.0978248*T + 0.0635950*Vt + 0.0131399*P + 0.0000878379*Gs^2 - 0.000816520*T^2 - 0.000205675*Vt^2 - 0.0000132106*P2 - 0.000127511*Gs*T - 0.0000342671*Gs*Vt + 0.0000210474*Gs*P - 0.0000236347*T*P$$

$$Qm = -0.133804 - 0.00216313*Gs + 0.00692672*T - 0.00222814*Vl + 0.00262284*Vt - 0.000479788*P + 0.00000750518*Gs^2 - 0.0000744781*T^2 - 0.0000117418*Vt^2 + 0.00000378292*Gs*T + 0.00000244522*Gs*P + 0.00000697266*Vl*P + 0.00000274229*Vt*P$$

- ***Models adjustment*:**

The empirical honing models have been adjusted using the test results of 27 tubes honed with different process parameters in an industrial honing machine. The experimental results has been compared to theoric results and a regression analysis has been done.





The relation between experimental and theoric results is lineal with a coefficient near 1 plus an independent parameter.

The definitive mathematical relations have been found for rough and semifinishing honing processes parameters for an industrial honing machine:

$$Ra = -4.34983 - 0.00398962*Gs + 0.0773905*T + 0.0322614*Vt + 0.00179538*P + 0.000073570*Gs^2 - 0.000604828*T^2 - 0.000105318*Vt^2 - 0.0000792654*Gs*T - 0.0000217231*Gs*Vt + 0.0000117975*Gs*P - 0.0000247565*T*P$$

$$Rt = -39.4117 + 0.00158608*Gs - 0.00476463*T + 0.381268*Vt + 0.0742900*P + 0.000462049*Gs^2 - 0.00131505*Vt^2 - 0.000086629*P^2 - 0.000660206*Gs*T - 0.00018077*Gs*Vt + 0.000073012*Gs*P + 0.000056499*Vt*P$$

$$Rq = -9.1722 - 0.00481193*Gs + 0.0978248*T + 0.0635950*Vt + 0.0131399*P + 0.0000878379*Gs^2 - 0.000816520*T^2 - 0.000205675*Vt^2 - 0.0000132106*P^2 - 0.000127511*Gs*T - 0.0000342671*Gs*Vt + 0.0000210474*Gs*P - 0.0000236347*T*P$$

$$Qm = -0.133804 - 0.00216313*Gs + 0.00692672*T - 0.00222814*Vl + 0.00262284*Vt - 0.000479788*P + 0.00000750518*Gs^2 - 0.0000744781*T^2 - 0.0000117418*Vt^2 + 0.00000378292*Gs*T + 0.00000244522*Gs*P + 0.00000697266*Vl*P + 0.00000274229*Vt*P$$

- ***Mathematical models for finishing honing processes***:

Empirical models for finishing honing have been done using the measures and data analysis of the test results using B5 and B20 as abrasive grain size, machined in an industrial honing machine.

♦ ***Results***:

$$Ra = 0.0699297 + 0.00343853 \cdot Gs - 0.00191320 \cdot Vl - 0.0000864898 \cdot P + 0.00000306549 \cdot Vl \cdot P$$

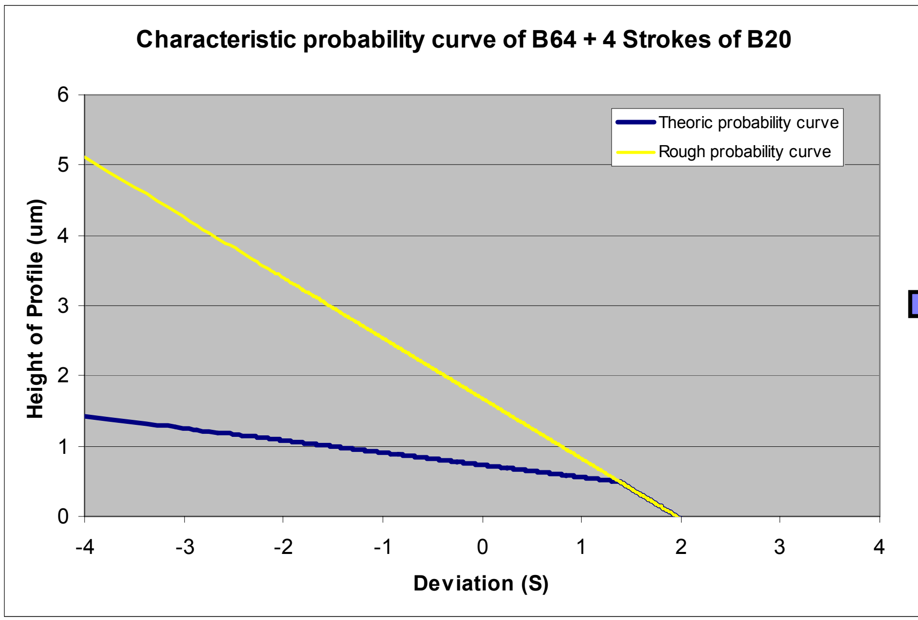
$$Rt = 1.35685 + 0.0988508 \cdot Gs - 0.0550005 \cdot Vl - 0.00248641 \cdot P + 0.0000881267 \cdot Vl \cdot P$$

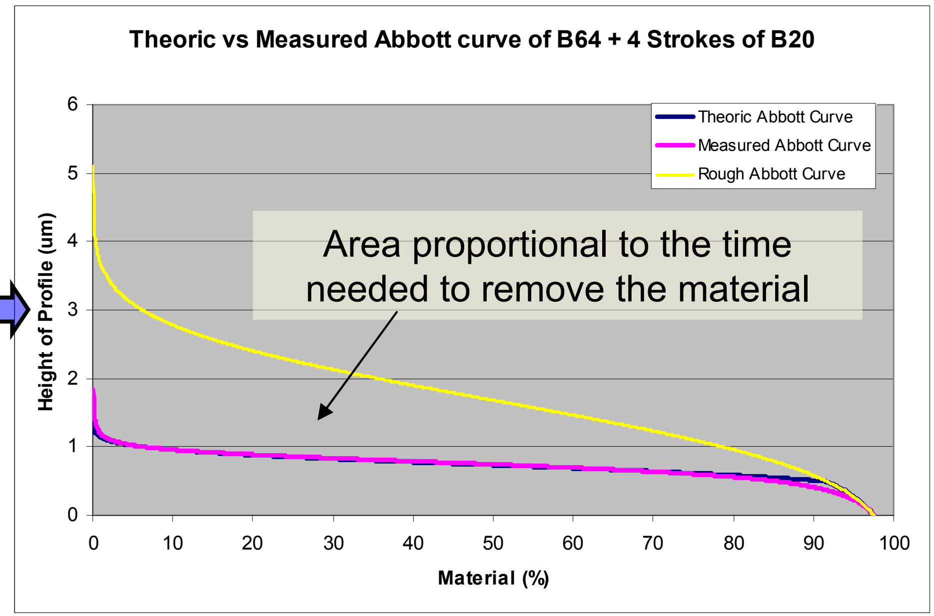
$$Rq = 0.106506 + 0.00685417 \cdot Gs - 0.00381365 \cdot Vl - 0.000172404 \cdot P + 0.00000611058 \cdot Vl \cdot P$$

$$Qm = -0.0173617 + 0.00140667 \cdot Gs - 0.000594583 \cdot Vl + 0.0000445673 \cdot P + 0.00000664167 \cdot Gs \cdot Vl$$

- ***Plateau-honing modeling*:**

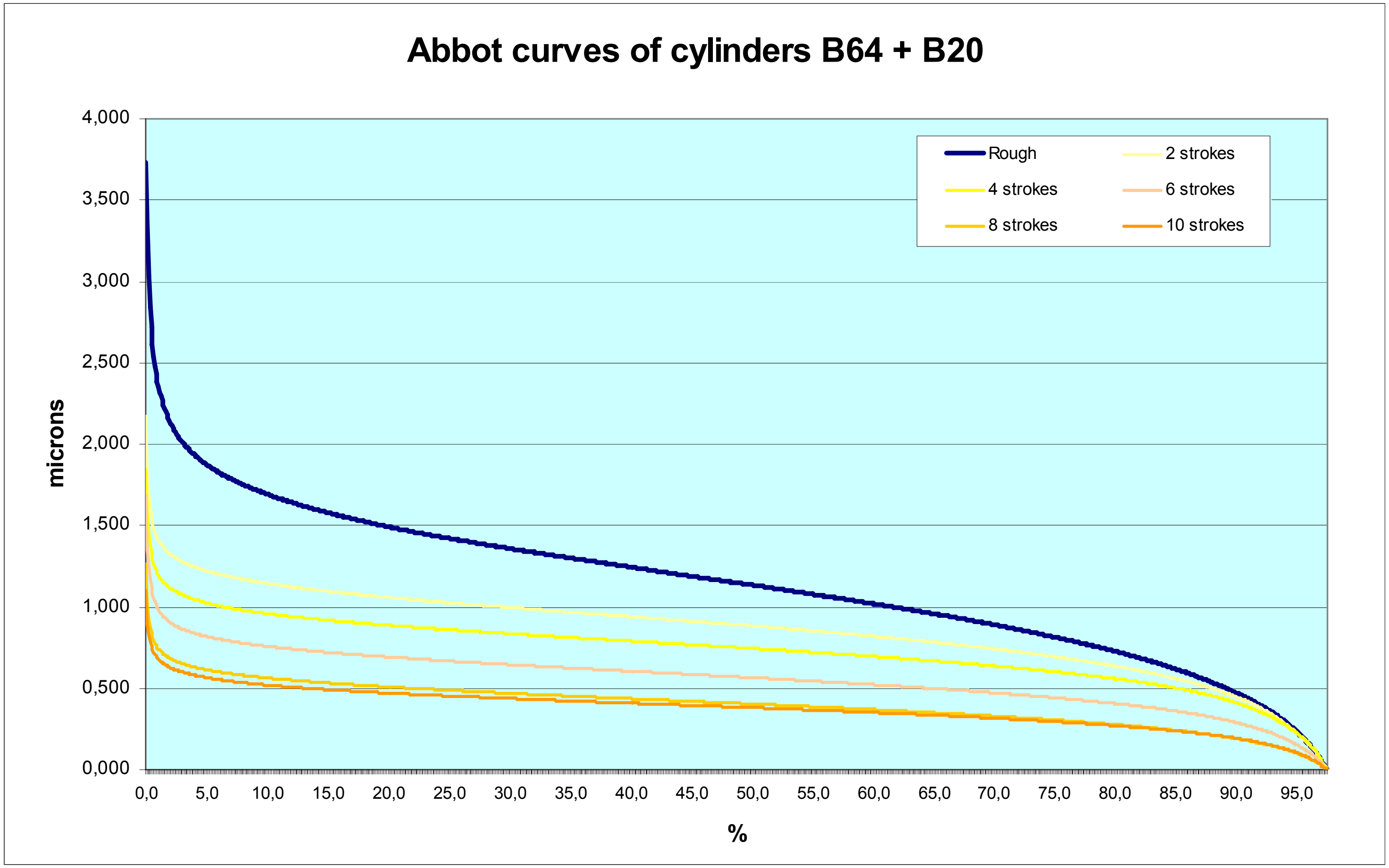
A new methodology based in to determinate the time of fine honing for getting a plateau-honing roughness texture defined by Rmq, Rvq, Rpq and α, has been developed, using the empirical relations found for fine and rough or semifinishing honing processes.



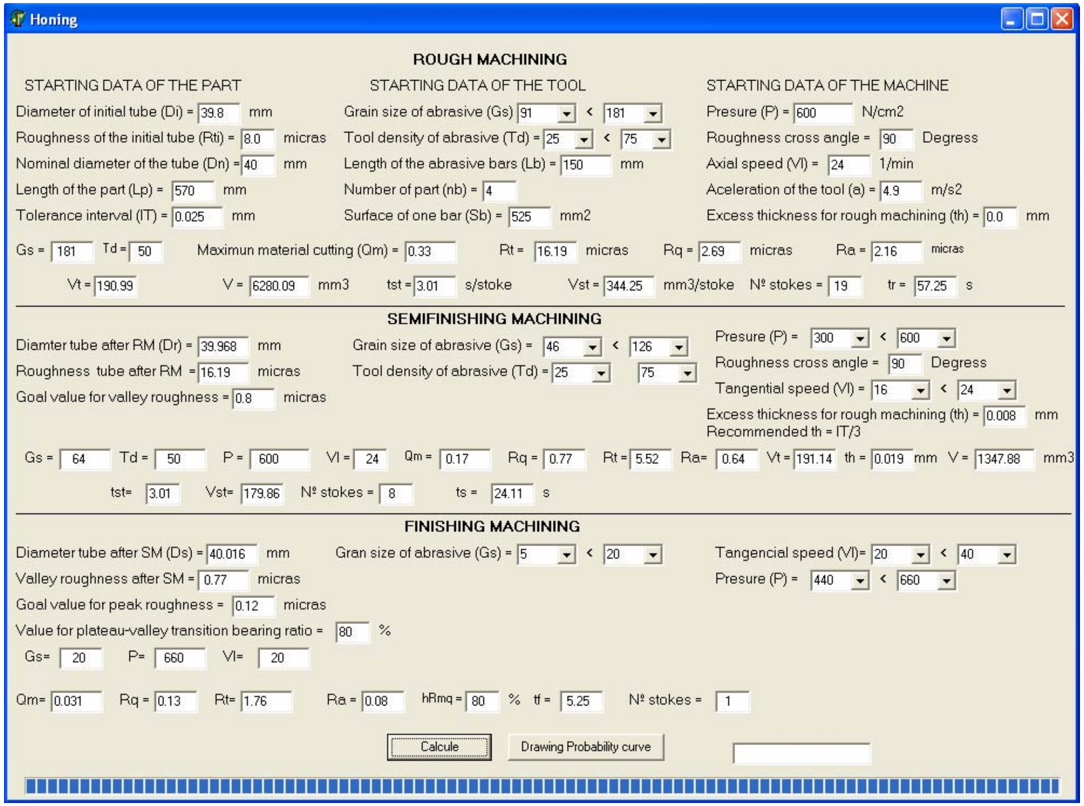


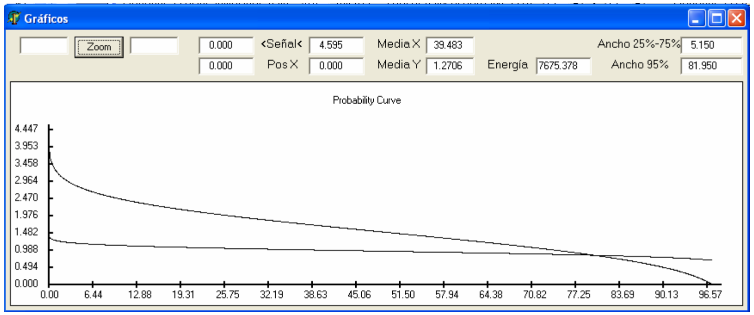
• ***Plateau-honing model implementation and validation:***

270 measurements of different plateau-honing processes have been done.



A computer program has been developed for plateau-honing full planning:





- ***Functional behaviour of the cylinder surface textures:***

The analysis of the hydraulic cylinder surface textures have been done.

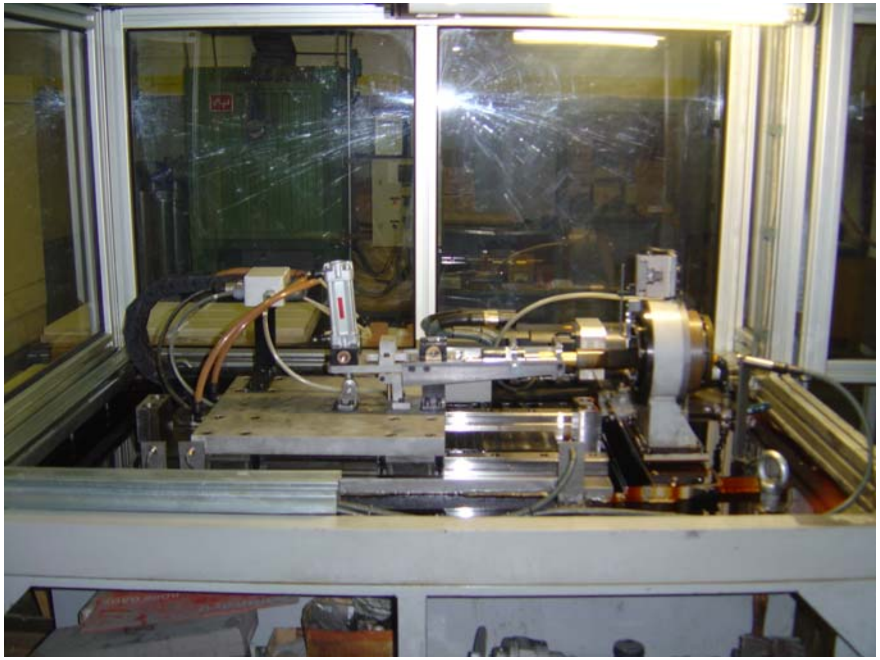
The ranges of values of roughness probability parameters for good functional behaviour of the hydraulic cylinders are

R_{mq} from 70% to 90%
R_{vq} from 0.4 µm to 1 µm
R_{pq} from 0.10 µm to 0.24 µm

• ***Ultrasonic assisted honing experimental tests:***

An ultrasonic assisted honing experimental test has been defined and performed, applying the ultrasonic vibration to the abrasive tool.

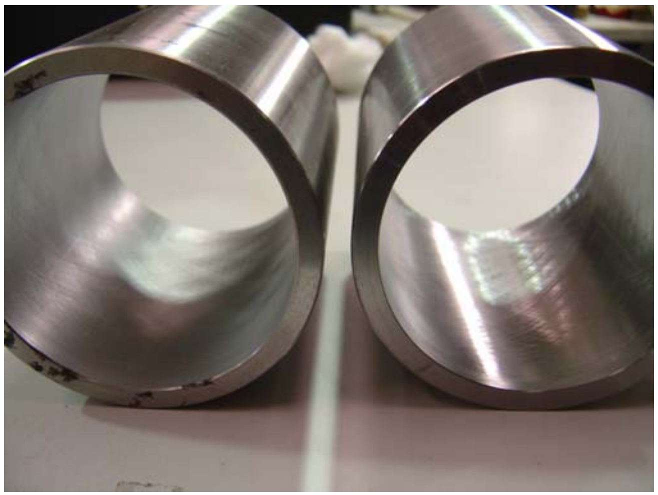
6 test-tubes have been machined using different ultrasonic vibration levels assisting honing processes in the abrasive test machine.



→ Effect of ultrasonic assistance in material removal and surface texture has been detected.

→ There have been a lot of problems with the welding of the abrasive tool and also with the repeatability of the tests.

UPC-CIM has analyzed sample tests in order to detect the ultrasonic assistance effect to honing processes.



Experiment	Ultrasonic frequency (Hz)	Ultrasonic Amplitude (µm)	Pressure (N/cm2)	Lineal speed (m/min)	Tangential Speed (rpm)	Ra (µm)	Rt (µm)	Rq (µm)	Rz (µm)
1009	-	-	300	24	100	1,2071	10,2610	1,5091	8,1420
1083	0	0	450	24	150	0,4276	4,4579	0,5576	3,4761
1034	0	0	450	24	150	0,6345	5,6755	0,8124	4,6332
1022	40.000	11,5	450	24	150	1,1111	11,0467	1,4416	8,2852
1078	40.000	11,5	450	24	150	0,5331	5,2009	0,6872	3,8710
246	40.000	18	450	24	150	1,0497	9,8566	1,3463	7,9663
1019	40.000	18	450	24	150	0,9112	7,7689	1,1489	6,4046

Experiment	Ultrasonic frequency (Hz)	Ultrasonic Amplitude (µm)	Pressure (N/cm2)	Lineal speed (m/min)	Tangential Speed (rpm)	Rk (µm)	Rpk (µm)	Rvk (µm)	Qm (cm/min)	Qt (mm3/min)
1009	-	-	300	24	100	3,7484	1,5473	1,6195	0,0150	0,1140
1083	0	0	450	24	150	1,1321	0,5189	0,9148	0,0147	0,4050
1034	0	0	450	24	150	1,9394	0,8565	0,9184	0,0273	0,3600
1022	40.000	11,5	450	24	150	3,5888	1,4986	2,0347	0,0917	0,5850
1078	40.000	11,5	450	24	150	1,6247	0,6824	0,8455	0,0451	0,0450
246	40.000	18	450	24	150	3,2818	1,7577	1,5906	0,0682	0,1350
1019	40.000	18	450	24	150	2,9321	1,3615	1,1043	0,0830	0,1350

→ It could be show that the ultrasonic assistance affects the surface texture and the material removal increases.

→ Stability problems affect the quantitative analysis.

T4.1.

CYLINDER BORE HONING

- Full project -

Objectives and contractors involved:

- MATHEMATICAL HONING MODEL:
  - To characterize the honing surface texture.
  - To obtain mathematical models for honing processes.
- SEMI-ANALYTICAL PLATEAU-HONING MODEL:
  - To characterize the plateau-honing surface texture.
  - To obtain a plateau-honing model.
- FUNCTIONAL BEHAVIOUR:
  - To analyze the functional behaviour of hydraulic cylinders vs surface texture.
- ULTRASONIC ASSISTED HONING:
  - To apply ultrasonic assistance in order to improve hydraulic cylinder surface texture and productivity.

Contractors involved:

- **Pedro Roquet S.A. (ROQUET)**
- **Honingtec S.A. (HONINGTEC)**
- **Trelleborg (TRELLEBORG)**
- **Universitat Politècnica de Catalunya (UPC-Cim)**

Research/work performed and final results:

• *Methodology for plateau-honing roughness characterization*:

- 225 roughness measurements (2D) and analysis.
- 41 roughness measurements (3D) and analysis.
- 2D-3D roughness parameters correlation.

Results:

- Proposed methodology for tubes roughness measurements.
- Roughness characterization of honed parts:
  Ra, Rt, Rq, Abbott Parameters (Rk, Rpk, Rvk) and α Cross Angle
- Roughness characterization of plateau-honed parts:
  Ra, Rt, Rq, Probability Parameters (Rmq, Rpq, Rvq) and α Cross Angle
- Large data base of roughness measurements.

• ***Honing process modelation***:

- 6 DoE with 5 parameters (47 experiments of each DoE).
- 27 tubes machined for adjustements.
- 32 tubes for finishing honing model.
- 3069 roughness measurements.

Results:

- Empirical rough and semifinishing honing relations.

$$Ra = -4.34983 - 0.00398962*Gs + 0.0773905*T + 0.0322614*Vt + 0.00179538*P + 0.000073570*Gs^2 - 0.000604828*T^2 - 0.000105318*Vt^2 - 0.0000792654*Gs*T - 0.0000217231*Gs*Vt + 0.0000117975*Gs*P - 0.0000247565*T*P$$

$$Rq = -9.1722 - 0.00481193*Gs + 0.0978248*T + 0.0635950*Vt + 0.0131399*P + 0.0000878379*Gs^2 - 0.000816520*T^2 - 0.000205675*Vt^2 - 0.0000132106*P^2 - 0.000127511*Gs*T - 0.0000342671*Gs*Vt + 0.0000210474*Gs*P - 0.0000236347*T*P$$

$$Rt = -39.4117 + 0.00158608*Gs - 0.00476463*T + 0.381268*Vt + 0.0742900*P + 0.000462049*Gs^2 - 0.00131505*Vt^2 - 0.000086629*P^2 - 0.000660206*Gs*T - 0.00018077*Gs*Vt + 0.000073012*Gs*P + 0.000056499*Vt*P$$

$$Qm = -0.133804 - 0.00216313*Gs + 0.00692672*T - 0.00222814*Vl + 0.00262284*Vt - 0.000479788*P + 0.00000750518*Gs^2 - 0.0000744781*T^2 - 0.0000117418*Vt^2 + 0.00000378292*Gs*T + 0.00000244522*Gs*P + 0.00000697266*Vl*P + 0.00000274229*Vt*P$$

- Empirical finishing honing relations.

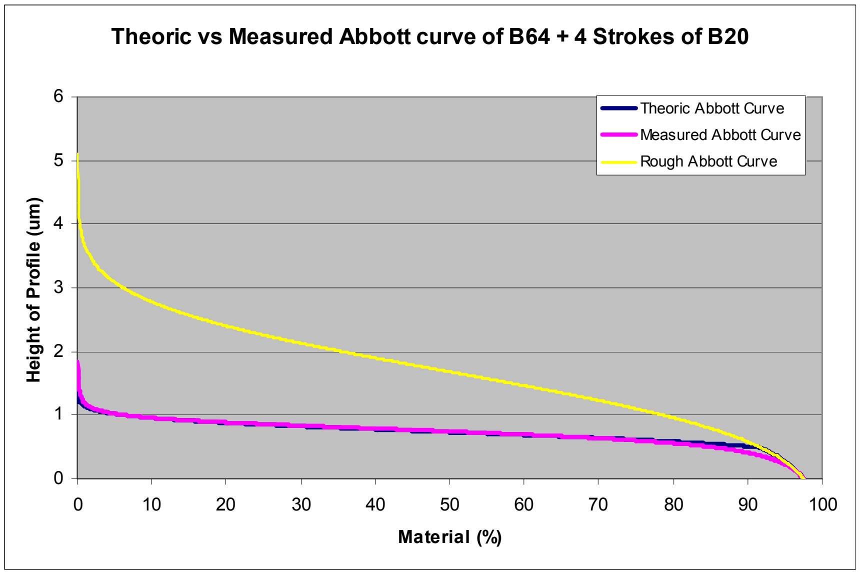
$$Ra = 0.0699297 + 0.00343853*Gs - 0.00191320*Vl - 0.0000864898*P + 0.00000306549*Vl*P$$

$$Rq = 0.106506 + 0.00685417*Gs - 0.00381365*Vl - 0.000172404*P + 0.00000611058*Vl*P$$

$$Rt = 1.35685 + 0.0988508*Gs - 0.0550005*Vl - 0.00248641*P + 0.0000881267*Vl*P$$

$$Qm = -0.0173617 + 0.00140667*Gs - 0.000594583*Vl + 0.0000445673*P + 0.00000664167*Gs*Vl$$

- ***Plateau-honing process modelation***:
  - 132 tubes plateau-honed whit different machining parameters.
  - 30 simulation of real and theoric Abbott curves fitting.



It has been checked the reability of using probability parameters for getting Abbott curve of plateau-honing parts and the possibility of estimate the fine honing time for removing the material between rough or semifinishing honing Abbott curve and plateau-honing Abbott curve.

Results:

- Computer program for the full plateau-honing process.

- ***Functional behaviour of hydraulic cylinders vs surface textures***:
  - Analysis of the results of the cylinders tested in the life cycle test benches.

Results:

- Range of values of roughness probability parameters for good functional behaviour.

R_{mq} from 70% to 90%
R_{vq} from 0.4 µm to 1 µm
R_{pq} from 0.10 µm to 0.24 µm

- ***Ultrasonic assisted honing experimental tests***:
  - Definition of the test.
  - Performance of the test.
  - 6 tubes machined with different ultrasonic vibration conditions.

Results:

- The ultrasonic assistance affects the surface texture and the material removal increases.
- There are stability problems that affects the results.
- It will be very difficult to apply ultrasonic vibration in the industrial honing machines.

Achievements of the research beyond the current State of the Art:

- ***New methodology to obtain a semi-analytical plateau-honing models.***
- ***New and more complete relations between machining parameters and roughness parameters for rough, semifinishing and fine honing and also for material rate:***

$$\boldsymbol{Ra, Rt, Rq, Qm = \varphi\,(Gst, TD, VL, VT, P)}$$

- ***Integration of complete process:***

rough honing + semifinishing honing + finishing (plateau-honing)

with a computer program.

- ***Large data base of roughness parameters.***
- ***Range of values of roughness probability parameters for good function behaviour of the hydraulic cylinders.***
- ***New experimental test of ultrasonic assisted honing, applying the ultrasonic vibration to the abrasive tool.***

Exploitable results list:

- Main exploitable result 1:
  Honing and plateau-honing process modelation.
- Main exploitable result 5:
  Tube surface roughness characterization.