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THE EFFICIENCY OF COMBINED MACHININGS

This paper analyses the efficiency of the finish process applied in machining of hard surfaces, completed by grinding, hard turning and also by the combination of these two procedures, on the basis of time consumption.

1. INTRODUCTION

In production engineering the complexity of components show an increasing tendency accompanied by higher quality requirements. Components with ever smaller roughness and ever more accurate geometrical formation are needed. Today's advanced production engineering can meet this double requirement by ready-machining of the components possibly on one machine-tool with one clamping only. According to this machine-tool industry provides a wide range of machine-tools capable to reach the goal. The ready-machining fulfilled with one clamping by several procedures is called combined machining. The necessary combined machine-tools are suitable to complete any series of procedures either in chuck-work or shaft-like parts. External and internal turning, grinding, boring, milling or even spark-cutting can be done on these machines. They are highly accurate and automated. A warrant for that is that the firms today producing combined machines one and all produced grinding machines before (Studer, Schaudt, Walter, Blohm, Körber, Emag, etc.). The biggest advantage of the combined machining is that the lead-time of parts dramatically reduces, and the production-chain is dramatically shorter. The transportation and storage times between the procedures completely cease, and also the size of side times significantly reduces. The productivity increases, the quality of the workpieces is better besides high flexibility.

2. THE OVERVIEW OF THE COMBINED PROCEDURES

The idea of combined machining comes from the integration of hard turning and grinding. Hard turning – with its characteristic speediness and flexibility – although accompanied by the accuracy characteristic of grinding, was not able to compete with grinding from the point of view of process safety and surface quality, Starting from this point emerged the concept of taking use of the high internal removal power and the flexibility of hard turning together with the reliability and high quality assurance of grinding. All this is to be done by one machine with one clamping. This philosophy of machining widened further and not only grinding and hard turning integrated on one machine but any other machining procedure, too, (e.g.: boring, milling, thread cutting, surface grinding, from grinding, etc.) even spark cutting [1].

The significant development of the pre-fabrication technologies also substituted to the fast spread of the combined proceedings. The pre-fabricated parts are made by the so called —near-net-shape" pre-fabrication procedures with minimal allowance for finishing, thus making the roughing procedures that leave a huge amount of chips unnecessary. As an example, in Figure 1 the working area o a high capacity combined machine-tool can be seen which is to fulfill chuck work. Naturally, there are also machines of horizontal arrangement with internal grinding spindles located on the turret.

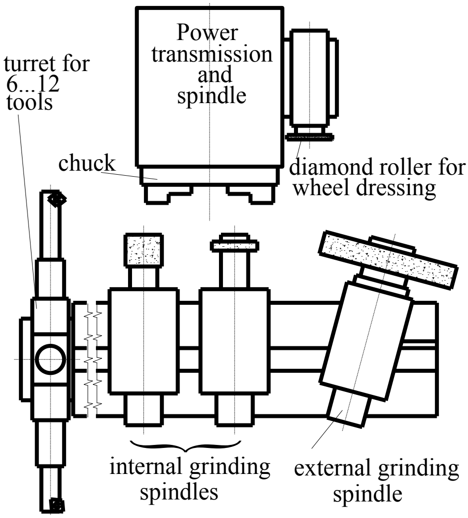


Figure 1 – Scheme of the working area of a combined machine-tool for machining disc-type components (Schaudt "Kombi Grind" [1])

The highest gain of changing from manufacturing on individual machines to combined machining is undoubtedly the drastic reduction of the lead-time and the remarkable shortening of the production-chain. Beyond those further benefits appear which can be listed in the following three groups:

- cease of errors from clamping (defining position),
- reduction of process allowance to its minimum,
- reduction of side-times and standard allowance.

As for the clamping errors, in bodies of revolution the errors from the repeated centralization are ceased, thus the cylindrical and conical surfaces having one shaft are made without any impact. But also cease the errors from the repeated setting on the support and the errors from positioning the distance measuring systems after each clamping.

The process allowance reduces mainly in bodies of revolution, because the errors from the repeated centralization are not to be compensated by allowance to avoid stains on the workpiece. For grinding, for example, allowance of range in micrometers in enough. In side-times, the times, to check the correctness of the repeated clamping, adjustment and measurement are ceased or significantly reduced [2].

3. APPLICATION OF COMBINED PROCEDURE IN FINISH MACHINING OF GEAR-WHEEL BODIES

Gear-wheels with bore-holes are made in big piece-number. From the point of view of technology they belong to the group of disc-type components. They are installed in gear-boxes, power-transmission boxes. Although their basic form is theoretically the same, minor differences occur by necessity, however, they do not affect the principle of their machining. Four typical examples of the examined components can be seen in Figure 2.

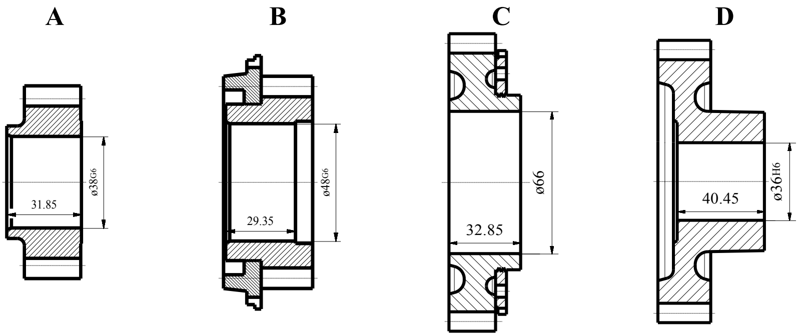


Figure 2 – Gear-wheels machined by combined procedure

The combined procedure is already the third version of the finish machining of gear-wheels with bore-holes. Grinding applied for a long time can be considered as the first version. Forasmuch through a remarkable stage of technological development there was no other possibility. The finish machining of hardened materials could only be grinding because there was not any other cutting tool suitable for hardened surfaces. Grinding in holes was a very slow process because the allowance of the range of tenth mm-s was to be removed by manufacturing passes of the range of micrometers. On the applied classic boring machines the speed of wheel is not higher than 25...29 m/s, the method is longitudinal feed, the control is by hand, which significantly increase the side-times.

The second version is hard turning. There were two conditions for the industrial application of hard turning: one was the tool material, the other one was the machine-tool that meets the emerging special requirements. Among the new advanced tool materials the cubic boron nitride (CBN) reached the phase of industrial application at the end of the 20^{th} century. The structural configuration according to ISO, with the small-sized CBN insert positioned on the peak made its application profitable. Almost in line with the development of inserts the machine-tools suitable for hard turning appeared in the market too. Their characteristic feature is the higher rigidity, high thermal stability, CNC control and advanced, quick workpiece clamping. Hard turning – because with one roughing and one smoothing clamp it finishes the workpieces – became the alternative process of grinding. Productivity dramatically multiplied by 4 to 5 having the same accuracy and roughness parameters as grinding.

However, as the experience increased, problems appeared in the field of hard turning with CBN. They fall in two categories: process safety and surface quality (topography). As regards to the process safety, the wear of CBN inserts – and through that their tool life – is difficult to be handled, the dispersion of the tool life of inserts is high. There are inserts whose tool life goes ruin sooner than given in the catalogue, others later, and there is also the danger of getting chipped. This phenomenon disturbs the safety of the manufacturing process. Because such a problem does not exist in grinding, it can be stated that the process safety of hard turning is worse than that of grinding. The surface quality (topography) problems occurs because hard turning makes a so called periodical surface, that is the surface consists of regularly repeating formation (thread-like). This although invisible to the naked eye, of microscope scale, but is disadvantageous in sealing surfaces, connecting surfaces and fixed junctions. In grinding, however, random topography is created, which is more beneficial in the above mentioned, critical cases. On this basis one can say that grinding is more beneficial, than hard turning from the point of view of surface quality.

Joining the two procedures, the third version of the finish machining of gear-wheels, the combined procedure comes into existence. The point of the combined machining is to maximally exploit the benefits of both procedures but not to allow their shortcomings to predominate. The flexibility and high material removal rate of hard turning are taken advantage of, and so are the process safety and the reliable quality assurance of grinding.

4. COMPARISON OF THE COMBINED PROCEDURE WITH THE FORMER VERSION

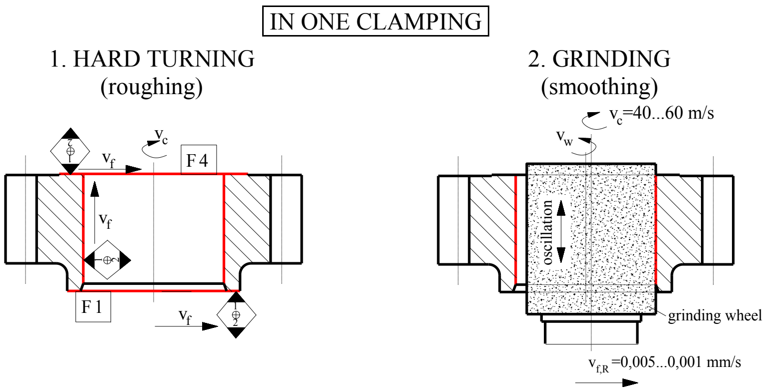
In gear-wheel bodies the surface of bore-holes and synchronizing cones are critical, not so much are the face surfaces. That is why only the machining of bore-holes (on each piece) and the connecting cones (on fewer pieces) is done by combined procedure. The three versions of machining concerning the bore-holes are shown in Figure 3.

Comparing the procedures, significant differences can be seen in three fields: the allowance, the feed and the grinding process. In the third version the allowance of hard turning reduced significantly: from 0.25 mm-s to 0.1 mm, however, that of grinding was minimal, not more than 0.05 mm-s. At the sometime the values of feed in hard turning increased significantly: the roughing feed increased from 0.15

mm/wp.rev to 0.24 mm/wp.rev. Thus the main machining time reduced 60 %. Bid feed, keeping the roughness unchanged, can be done only by Wiper-insert. The reduction of the main machining time by Wiper-insert and big feed compensates the longer machining time of smooth boring as opposed to smooth turning. That explains why the machining time of the combined procedure does not increase or just to a small degree. There is significant difference between the grinding procedures. Instead of the traditional longitudinal feed procedure (1st version), in the third version a high speed infeed procedure is applied. The material removal rate of this is higher than that of the first procedure, but it requires a for more rigid machine and a for more rigid grinding spindle. These requirements of higher rigidity are met by the turning-grinding machines of advanced structure. Beyond that, the grinding procedure replacing the smooth turning is automated including wheel-dressing too. The processes of the combined procedure are indicated in Figure 4.

1st process	2nd process	3rd process
GRINDING	HARD TURNING	COMBINED PROCEDURES
1. Roughing Allowance: 0.25 mm 2. Smoothing Allowance: 0.05 mm 3. Sparking out	1. Roughing Allowance: 0.25 mm Feed: 0.15 mm/rev 2. Smoothing Allowance: 0.05 mm Feed: 0.08 mm/rev 3. —	1. Rough turning Allowance: 0.27 mm Feed: 0.24 mm/rev 2. Smooth grinding Allowance: 0.05 mm 3. Sparking out

Figure 3 – Three versions of finish precision machining of bores in hardened gear-wheels



Centralization and clamping: on pitch circle
Vertical impact: on face surface indicated F4

Figure4 – The practical completion of the combined machining

It is eye-catching that beside the vertical construction the positioning of the workpieces goes with a converse support system: they impact in the direction of the shaft under the influence of not the gravitational force but the clamping force of the loading device. Thus the positioning elements of the clamping device remain clean because the chips fall of them.

5. THE TECHNOLOGICAL PARAMETERS AND TIME CONSUMPTION OF PROCEDURE VARIATIONS

Table 1 summarizes the technological and wheel data of the oldest version – grinding – concerning the four gear-wheels shown in Figure 2. At the bottom of the table calculated time data appear: namely the machine time, the basic time and the piece time. The piece time was defined by the method used at the plant.

Parameters and time consumption (1st version) Table 1

Symbols			A	B	C	D	Material: 16MnCr5 61…63 HRC
Right face (RF)	a_e	mm	0.03 0.01	0.03 0.01	0.03 0.01	0.03 0.01	Wheel: ∅50x40x13/25x20-9A80-K7V22
	v_w	m/min	15	15	15	15	
	v_c	m/s	30	30	30	30	
Left face (LF)	a_e	mm	0.03 0.01	0.03 0.01	0.03 0.01	—	Wheel: ∅103/94x38x180 FORM1458
	v_w	m/min	15	15	15	—	
	v_c	m/s	30	30	30	—	
Bore roughing and smoothing	n_k	2st/min	36 33	40 36	38 35	28 26	Wheels: ∅30x40x16-9A80-K7V22 ∅40x40x16-9A80-K7V22 ∅50x40x16-9A80-K7V22 side feed boring
	f	mm/wp.rev.	13.75 12.50	24.44 22.22	24.44 22.22	13.75 12.50	
	a_e	mm/2st	0.020 0.001	0.010 0.001	0.010 0.001	0.030 0.0015	
	$v_{f,L}$	mm/min	2200 2000	2200 2000	2200 2000	2200 2000	
	v_w	m/min	19.1	13.6	18.7	18.1	
	v_c	m/s	25	29	29	25	
	i_k	—	8	16	16	16	
Cone	a_p	mm	—	8.65	—	—	Wheel: ∅600x25x30469A80-J8V infeed external cylindrical grinding
	$v_{f,R}$	mm/s	—	0.009 0.003	—	—	
	v_c	m/s	—	32	—	—	
Machine time [min]			2.55	4.33	3.30	2.47	$T_{machine}=T_{main\ machine}+T_{side\ machine}$ $T_{basic}=T_{machine}+T_{change}+T_{else}$ $T_{change}=T_{else}=0.2$ min $T_{piece}=1.15\cdot T_{basic}$
Basic time [min]			3.35	5.53	4.10	2.87	
Piece time [min]			3.81	6.36	4.72	3.31	
Note: in the case of two values, the upper one is for roughing, the bottom one is smoothing.							

Interpretation of the symbols applied in Table 1:

a_e – depth of cut: mm f – feed: mm/wp.rev.

v_w – workpiece rate: m/min $v_{f,L}$ – feed rate (longitudinal): mm/min
v_c – wheel rate: m/s $v_{f,R}$ – feed rate (radial): mm/s
n_k – number of double stroke: 2st/min i_k – number of sparking out stroke: —
a_p – grinding width (in cones): mm

In the procedure the time appropriation is the biggest. Serving the small powered boring machines takes a lot of side time. A significant part of that is the side time for dressing which has to be done very often, sometimes after each workpieces.

Compared the 1st version, the introduction of hard turning was a great leap forward. Table 2 contains its cutting data, the specifications of the tools as well as the data of time appropriation.

The parameters and time consumption of hard turning (2nd version) Table 2

Symbols			**A**	**B**	**C**	**D**	Material: 16MnCr5 61…63 HRC
Right face (RF)	a_p	mm	0.3	0.3	0.3	0.3	
	f	mm/wp.rev.	0.08	0.08	0.08	0.08	
	v_c	m/min	194	204	180	242	Insert for roughing:
Left face (LF)	a_p	mm	0.3	0.3	0.3	—	CNMA 120408
	f	mm/wp.rev.	0.08	0.08	0.08	—	Insert for smoothing:
	v_c	m/min	204	228	185	—	CNGA 120408
Cone	a_p	mm	—	0.3	—	—	Coating: TiN
	f	mm/wp.rev.	—	0.12	—	—	Facet: 0.2x -20°
	v_c	m/min	—	224	—	—	
Bore roughing	a_p	mm	0.25	0.25	0.25	0.25	
	f	mm/wp.rev.	0.15	0.15	0.15	0.15	
	n_w	1/min	1508	1195	869	1597	
Bore smooth-ing	a_p	mm	0.05	0.05	0.05	0.05	
	f	mm/wp.rev.	0.08	0.08	0.08	0.08	
	n_w	1/min	1508	1195	869	1597	
Machine time		[min]	0.57	0.85	0.97	0.61	$T_{machine}=T_{main\ machine}+T_{side\ machine}$
Basic time		[min]	0.77	1.05	1.17	0.81	$T_{basic}=T_{machine}+T_{change}+T_{else}$ $T_{change}=T_{else}=0.2$ min
Piece time		[min]	0.92	1.26	1.41	0.97	$T_{piece}=1.15\cdot T_{basic}$

α	γ	ε	κ_{eff}	λ	r_ε
6°	-26°			6°	0.8

Interpretation of the symbols applied in Table 2:
a_p – depth of cut: mm v_c – cutting speed: m/min
f – feed: mm/wp.rev. n_w – wp. revolution: 1/min

The time appropriation reduces 1/4...1/5 of grinding. Besides, while grinding needs 2 to 3 machines, hard turning require only one. The cutting data of the combined procedure, the specification of the tools and the time appropriation are seen in Table 3.

The parameters and time consumption of the combine procedure (3rd version) Table 3

Symbols			A	B	C	D	Material: 16MnCr5 61…63 HRC
Right face (RF)	a_p	mm	0.1	0.1	0.1	0.12	
	f	mm/wp.rev.	0.1	0.1	0.1	0.1	
	v_c	m/min	180	140	180	200	
Left face (LF)	a_p	mm	0.1	0.1	0.1	—	Insert: CCGW 09T308 NC2 (SUMITOMO)
	f	mm/wp.rev.	0.1	0.1	0.08	—	Insert clamping:
	v_c	m/min	140	140	180	—	C5-SCLCR 11070-09 (SUMITOMO)
Cone	a_p	mm	—	0.12	—	—	
	f	mm/wp.rev.	—	0.1	—	—	
	v_c	m/min	—	140	—	—	
Bore roughing (BR)	a_p	mm	0.1	0.1	0.1	0.1	
	f	mm/wp.rev.	0.24	0.24	0.24	0.24	f=0.12 is for a short bore
	v_c	m/min	180	180	180	180	
Internal grinding			Parameters of grinding are in Table 4				
Cone grinding			—	Parameters of grinding are in Table 4	—	—	
			—		—	—	
			—		—	—	
Machine time [min]			—	—	—	—	
Floor-to-floor time [min]			1.230	1.420	1.430	1.056	
Norm time [min]			1.279	1.477	1.487	1.098	

As for the time appropriation, its reduction is very small, there are cases, were the floor-to-floor time is even more than in hard turning (2nd version). The norm time, however, is smaller with all the four wheel than in hard turning. The reason for that is that the method of norm time calculation has changed too. The point of the change is that in combined procedure the sum of allowances to be added to the floor-to-floor time is not more than 1/5 of the calculated allowances in hard turning.

That way the increasing floor-to-floor times in the combined procedure do not mean norm time increase at the some time. Because the parameters of the grinding process within the combined procedure are lengthy, they are summarized in a separate table and there is given the interpretation of symbols too (Table 4).

Grinding parameters in combined procedure Table 4

Symbols			**A**	**B**	**C**	**D**	Material: 16MnCr5 61…63 HRC	
Internal grinding	$\mathbf{v_c}$	m/s	40	40	40	40	wheel circumferential velocity	***Process***: infeed internal grinding with oscillation ***Dressing***: after each third wp. automatically
	$\mathbf{v_w}$	m/min	45	86	119	65	wp. circumferential velocity	
	$\mathbf{v_{f,R}}$	mm/s	N:0,0050 S:0,0036	N:0,0050 S:0,0033 0,0016	N:0,0033 S:0,0016	N:0,0050 S:0,0016 0,0010	infeed velocity	
	q	—	53	27	20	37	velocity quotient	
	$\mathbf{t_{so}}$	s	6	5	8	5	sparking out-time	
	$\mathbf{L_o}$	mm	3.0	2.5	2.0	2.5	oscillation stroke length	
	$\mathbf{v_o}$	mm/min	600	600	600	600	oscillation velocity	
	$\mathbf{n_k}$	1/min	100	120	150	120	number of double strokes	
	Z	mm	0.040	0.045	0.050	0.050	grinding allowance,	
	$\mathbf{Z_N}$	mm	0.030	0.030	0.040	0.035	roughing allowance,	
	$\mathbf{Z_s}$	mm	0.010	0.010 0.005	0.010	0.010 0.005	smoothing allowance in diameter	
Cone grinding	$\mathbf{v_c}$	m/s	—	45	—	—	wheel circumferential velocity	***Process: infeed external cylindrical grinding*** ***Dressing:*** *after each wp.*
	$\mathbf{v_w}$	m/min	—	98	—	—	wp. circumferential velocity	
	$\mathbf{v_{f,R}}$	mm/s	—	N:0.0080 S:0.0016 0.0013	—	—	infeed velocity	
	q	—	—	28	—	—	velocity quotient	
	$\mathbf{t_{kisz}}$	s	—	6	—	—	sparking out-time	
	Z	mm	—	0.050	—	—	grinding allowance,	
	$\mathbf{Z_N}$	mm	—	0.035	—	—	roughing allowance,	
	$\mathbf{Z_s}$	mm	—	0.010 0.005	—	—	smoothing allowance in diameter	

It is also worth highlighting that instead of the machine time, the floor-to-floor time gives the basis of all time related calculations. The machine time does not even appear in the technological documentations, thus it could not get into Table 3 either. Namely the machine time consists of two parts: main machine time ant side machine time. The former can exactly be calculated, but the second part cannot, which may lead to disagreement. However, the floor-to-floor time can be measured precisely, therefore it is exact and beyond controversy.

Finally, the time data of the three examined procedures that can be compared are outlined as time appropriations in bar graphs. In Figure 5 a case can be seen when the floor-to-floor time reduces and the norm time significantly reduces. Similar is the case of the gear wheel in Figure 6. Figure 7 shows a case when the floor-to-floor time increases in the combined procedure, the norm time, however, slightly reduces compared to hard turning. In the case of Figure 8 (gear wheel number 044) the floor-to-floor time is practically the same, the norm time, however, slightly reduces.

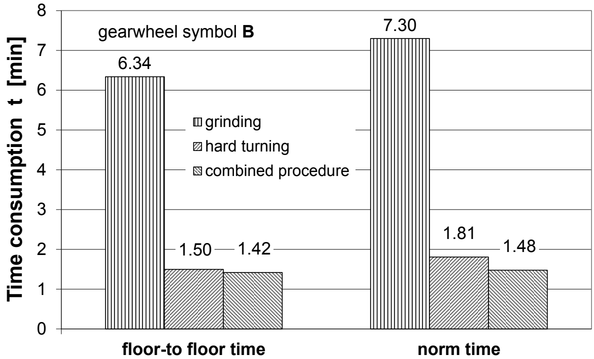


Figure 5
Reducing floor-to-floor time, more reducing norm time

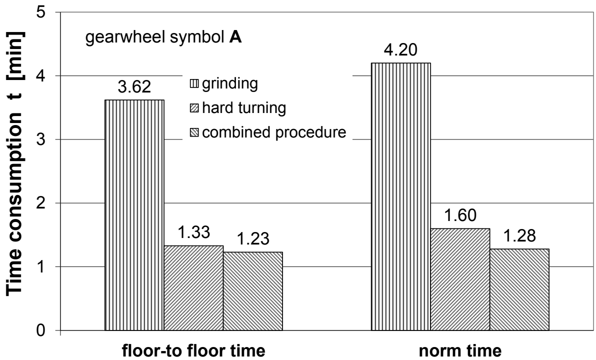


Figure 6 – Smaller floor-to-floor time, smaller norm time

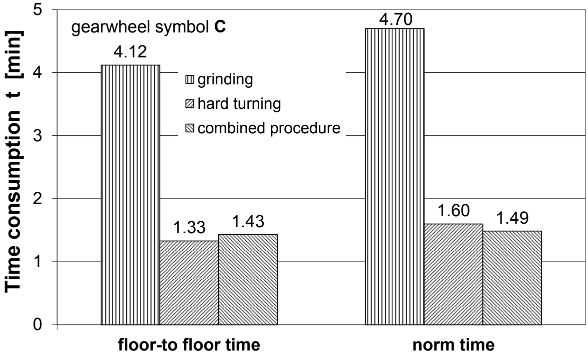


Figure 7 – Smaller norm time even when higher floor-to-floor time

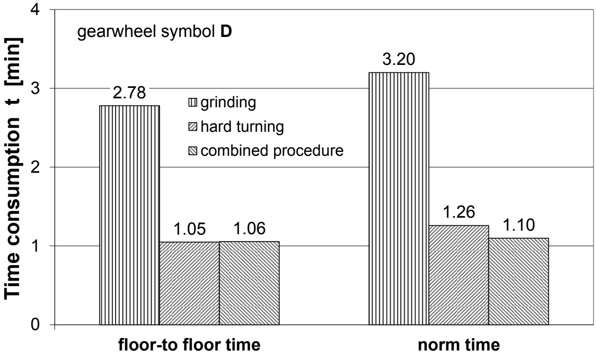


Figure 8 – Norm time is smaller in combined procedure in the case of almost equal floor-to-floor time

The average floor-to-floor time of the four examined wheels is 1.415 min in hard turning, 1.410 min in the combined procedure, they are practically equal. However, the average norm time is 1.57 min in hard turning, 1.33 min in the combined procedure that is smaller by 0.24 min, which means a 15 % reduction.

6. DISCUSSION

The combined machining of workpieces on one machine-tool, applying different procedures increases the quality of workpieces and reduces the side times. That is why this technology has become outstandingly interesting for engineering. In finishing of hardened workpieces, too, it can be applied successfully instead of hard turning. But because internal grinding replacing smooth turning takes longer time, if the rough turning is kept unchanged the time consumption (floor-to-floor time) would increase. To avoid that the time for hard turning is to be reduced which, keeping the roughness unchanged, can be reached by increased feed, with Wiper-inserts. In the four examined wheels the feed had to be increased by 60 % so that not increase the floor-to-floor time. The tool expenditure was slightly higher, because Wiper-insert is somewhat more expensive than the usual ISO insert. In the field of wage costs the situation norm time allowances, the wage costs of the combined procedure reduced in each case. The explanation for that is that the complete machining done on highly automated machines with one clamping requires much less side time. In the examined cases the norm-time-constituting allowances added to the floor-to-floor time reduced to its 1/5 compared to hard turning.

It also must be noted that because of the grinding process application of coolants and lubricants came back to the system. It means higher expenditure compared to the dry hard turning. Paying attention to the trends, however, it is not inconceivable that as the grinding technique develops, it will be possible to work with minimal lubrication or even dry grinding.

7. SUMMARY

Applying the combined machining the workpiece quality improves, the side times reduce. Besides, the process safety is appropriate, too, because the uncertainties in connection with the wear of CBN inserts are not to be counted on. The combined machining has got several beneficial features, among the time appropriations were examined. It was stated that among the three procedure versions the oldest one – grinding – requires the longest time. The next version – hard turning – means dramatic time reduction, while the third version compared to the second one means only minor reduction of time appropriation. And that appears mainly in norm time. Besides, the quality of work and the safety of the manufacturing process improves significantly.

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REFERENCES: [**1**] Peter Lütjens: Große Vorteile durch Kombinationsbearbeitung, Werkstatt und Betrieb 9/2008 pp.114-120.; [**2**] Karpuschewski – Wehmeier - Inasaki: Grinding Monitoring System Based on Power and Acoustic Emission Sensors, Annals of the CIRP 49/1//2000 pp.235-240.; [**3**] Denkena – Hahnmann – Mayer: Wie die Zukunft bei Schleif-, und Hartdrehenprocess aussieht, Werkstatt und Betrieb, 1-2/2009 pp.46-50.; [**4**] Löhmann, B. – Eisel, R.: Gelungene Vereinigung, Kombination Hartdrehen und Schleifen, Werkstatt und Betrieb, 1-2/2009 pp.64-65.

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