LANDTECHNIK 70(5), 2015, 194–202
DOI:10.15150/lt.2015.2675

Optimization potential of a standard tractor in road transportation

Michael Mederle, Adrian Urban, Hubert Fischer, Ulrich Hufnagel, Heinz Bernhardt

In numerous farms road transportation is of high importance in the task range of a standard tractor. During the harvest of grain or biomass as well as during the application of organic substrates a certain number of tractors exclusively runs on the road. The present study shows under practical conditions opportunities to optimize standard tractors for road transportation with acceptable effort to increase machine utilization and process efficiency at the same time. By realizing certain optimizing measures fuel consumption can be reduced by 11.4 % on average. Increasing the maximum speed from 50 to 60 km/h results in time savings of 8.5 % on average, causing a 5.5 % higher fuel consumption on average. The benefits of the examined optimization measures always have to be judged farm- and situation specifically.

Keywords
Agricultural logistics, Road transportation, Tire comparison, AG tires, Industrial tires, Efficiency

Transportations of any kind play an increasingly important role in agriculture. Growing farms, the gradually centralization of agricultural trading houses and sales opportunities as well as new branches of industry, such as biogas production, lead to an increasing effort in logistics (Götz 2011). Thereby not only the quantity of goods to be transported but also the transportation distance is continuously rising (Bernhardt 2014). Previous examinations already show that nearly 40 to 50 % of the required working time in arable farming is due to transport, handling and storage (Fröba 1994, Mührel 1974). Figure 1 shows the proportion of the agricultural transport volume compared to the commercial freight transport in Germany in 2014.

The domestic German freight logistics is dominated by road transport, both in terms of haulage mass (3.5 billion tons) as well as hauling capacity (467 billion ton kilometers) which is defined as product of transported mass in tons and average transportation distance in kilometers. As a result, the average haul distance is 134 km for road haulage. Considering the quantity of transported goods agriculture is in the second place with about 500 million tons, even before railroad (365 million tons) and inland shipping (229 million tons). Regarding hauling capacity agriculture is in the last rank with 8.0 billion ton-kilometers. This is due to relatively low haul distances of 16 km on average (Statistisches Bundesamt 2015, KTBL 2013 and Bernhardt 2014).

Concerning soil protection and sustainable conservation of the soil structure general splitting of field and road transportation would be desirable. For each particular requirement vehicles with large footprints in the fields and trucks with fuel-efficient high-pressure tires on the road offer the best solution possible in terms of weight, tire abrasion or fuel consumption (Reckleben et al. 2013).

However, due to short distances between fields and farm of 4 km on average single-phase logistics systems are widely spread especially in grain or biomass transport. A combination of standard tractor and trailer transports the goods directly from the harvester to the storage or to the silo. In case of

received 31 July 2015 | accepted 21 September| published 19 October

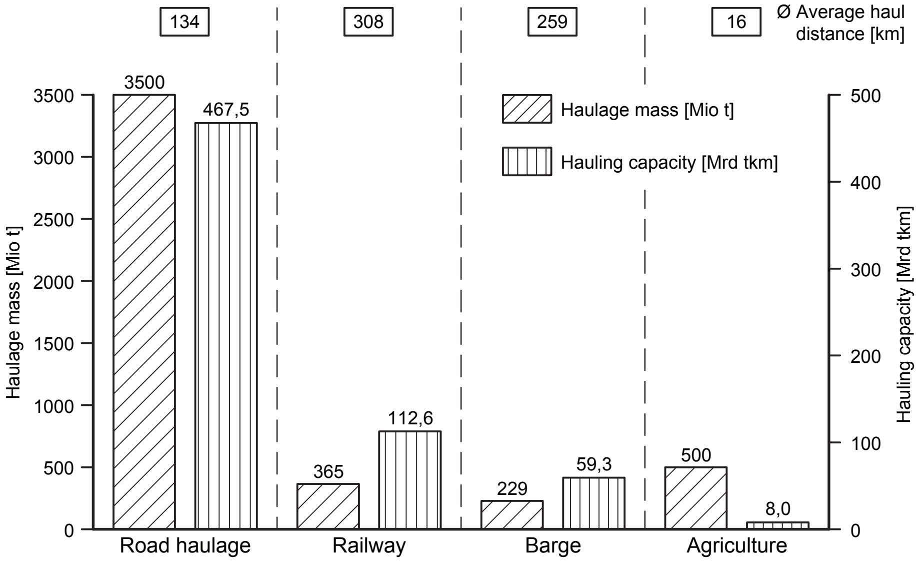

Figure 1: German domestic transport volume 2014 (Statistisches Bundesamt 2015, KTBL 2013, Bernhardt 2002 and own calculations)

multiphase transport chains field and road transportations are completely decoupled. However, this is only profitable if an extensive range of machinery and complex technology is available.

For decoupling field and road transportation in multiphase logistic systems it is not inevitably necessary that a truck has to be used on the road. Tractors as general-purpose machines are becoming more and more expensive both in purchase and in maintenance. Hence they require a workload which is as high as possible. For this reason in most farms they are also generally used for road transportation – although without being optimized in terms of lower fuel consumption and tire abrasion.

Former studies already examined various measures to reduce fuel consumption and to increase efficiency. Lindgren and Hansson (2002) determined fuel savings amounting to 2, 6 and 14 % for tractors with continuously variable transmissions used in road transportation by reducing the engine speed from 2000 rpm to 1800, 1600 and 1400 rpm.

In their examination on fuel consumption of varying motorized transport units Jílek et al. (2008) demonstrate that fuel demand may differ by up to 27 %, depending on the selected tractor performance. The tractor with the highest rated power requires the highest amount of fuel per ton-kilometer. However, this one has the highest transport volume per hour.

Udompetaikul et al. (2011) show in their examination that fuel efficiency of a tractor running in road transportation can be increased easily by approximately 10 %. Raising the tire pressure from 62 kPa to 110 or 158 kPa results in fuel savings of 7.3 and 11.4 % respectively.

In their comparison between AG tires and industrial tires Reckleben et al. (2013) obtained fuel savings of 18.2 % on average by using industrial tires in a mixed use of field and road work. This study focused on operations such as swathing, straw baling or the removal of grass silage, which require significantly lower pulling forces than e. g. ploughing or conservation soil tillage. When considering road transportation exclusively, fuel demand of industrial tires is lower by about 10.3 % on average due to the lower rolling resistance of paved roads.

According to surveys tractor tires are said to be used up to 30 % in road transportation (Hörner 2011). For this reason the present study is intended to focus on the optimization potential of a transport unit consisting of a standard tractor and a trailer in road transportation. The target variables were fuel consumption and lap time.

Materials and method

Eight different variants have been compared and analyzed under practical conditions. They differed in terms of tractor tires – and thus in reduction of weight –, loading conditions and maximum speed (Table 1). In addition to changing the tires all parts of the rear linkage which are not needed for road transportation – upper/lower arms, side stabilizers and lifting struts – have been dismantled to reduce the empty weight of the tractor and to increase the payload of the trailer.

Table 1: Overview of the experimental variants

Tractor tires	Loading condition of the trailer	Maximum speed [km/h]	Variant
AG tires	unloaded	50	1
		60	2
	loaded	50	3
		60	4
Industrial tires	unloaded	50	5
		60	6
	loaded	50	7
		60	8

Both types of tires have been analyzed for maximum speeds of 50 and 60 km/h as well as for trailer loading conditions ‘loaded’ and ‘unloaded’. When fully loaded the transport unit had a gross vehicle weight of exactly 40 tons. The tractor trailer combination to be tested consisted of a Fendt 828 Vario and a Krampe Roadrunner DA 34 (Figure 2).

Figure 2: Transport unit consisting of a Fendt 828 Vario and a Krampe Roadrunner DA 34 (Photo: M. Mederle)

The special feature of this new trailer concept is that the 3-axle trailer is able to transfer two to four tons of vertical load on the tractor depending on the permissible maximum speed. Thus the trailer has a gross vehicle weight of up to 34 tons. Each variant is repeated three times, thus the experiment is based on 24 test runs on a defined test track of 33.9 km length and 440 meters of altitude. The test track is classified in three different parts: ‚in town‘ (3.14 km), ‚cross-town‘ (23.92 km) and ‚urban traffic’ (6.84 km). Changing conditions along the route, e. g. uphill and downhill passages of up to 5 %, make the test course a representative and practical transport route for Southern German agriculture. Due to the renunciation of highways and motor roads tractors are allowed to pass the whole circuit. The classification of the individual route sections was conducted in a uniform model (Herrmann 2000) to be able to compare the results with previous driving tests (Engelhardt 2002, Götz 2011). Table 2 shows the tire types used for the experiment as well as the corresponding sizes and pressures.

Tabelle 2: Overview of used tires and pressures

	Designation	Front axle		Rear axle	
		Size	Pressure [bar]	Size	Pressure [bar]
AG tires	Michelin AxioBib	600/70R30	1.2	710/70R42	1.4
Industrial tires	Nokian TRI 2	440/80R34	3.2	620/80R42	3.2

In the standard versions with AG tires the tractor was equipped with Michelin AxioBib 600/70R30 in the front and 710/70R42 in the rear. The pressure was chosen according to the load capacity at 60 km/h given in the inflation table and represents a compromise between field and road use. In the optimized versions industrial tires of the type Nokian TRI 2 have been used. The size 440/80R34 was mounted in the front and 620/80R42 in the rear. The inflation pressure was adjusted to the maximum permissible 3.2 bar, so that the lowest rolling resistance possible could be ensured. In all variants the trailer has been equipped with Alliance Flotation 396 HS tires which are optimized to road transportation (pressure 6 bar) and had a size of 445/65R22.5. Table 3 shows the weights of both variants and the resulting payloads.

Table 3: Overview of empty weights and payloads of the experimental variants

	Standard version (AG tires, incl. rear linkage)	Optimized version (industrial tires, excl. rear linkage)
Empty weight tractor [kg]	10,680	10,240
Empty weight trailer [kg]	10,760	10,760
Empty weight transport unit [kg]	21,440	21,000
Payload [kg]	18,560	19,000

In the standard version with AG tires and rear linkage as standard the tractor had an empty weight of 10,680 kg. For the optimized versions this number could be reduced by 440 kg to a total of 10,240 kg. Weight savings of 210 kg have been achieved due to the lighter industrial tires and 230 kg by disassembling all parts of the rear linkage not needed for road transportation. The weight of the Krampe Roadrunner was 10,760 kg. The empty weight of the transport unit was 21,440 kg for the standard variant and 21,000 kg for the optimized version. This finally resulted in payloads of 18,560 kg (standard version) and 19,000 kg (optimized version) respectively. Both the variants with 50 km/h maximum speed as well as those at 60 km/h were carried out by the same tractor. The particular maximum speed has been set and held by the cruise control.

The measuring method was based on the standard of the DLG test center (Degrell et al. 2003). The fuel consumption was determined volumetrically. Therefore an oval wheel flowmeter of the type AIC-6004 Swiss Line Uniflowmaster (Automotive Information and Control Systems) has been retrofitted which operates according to the principle of displacement. In accordance to the manufacturer this measurement tool has an accuracy of ± 1 % and a reproducibility of ± 0.2 % (AIC 2011). Additionally a PT100 temperature sensor is integrated in the instrument for continuously detecting fuel temperature. The data of consumption and temperature have been recorded with a frequency of 1 Hz. The fuel consumption has been set off against the fuel temperature and then presented in g /100 km.

Results

Figure 3 shows the fuel consumption of the two examined tractor concepts both for trailer loading conditions ‚loaded' and ‚unloaded' as well as for maximum speeds 50 and 60 km/h. The figures represent the average values of the three repetitions of the respective variants. The values of the individual test runs do not vary more than ± 3 % around the corresponding average value.

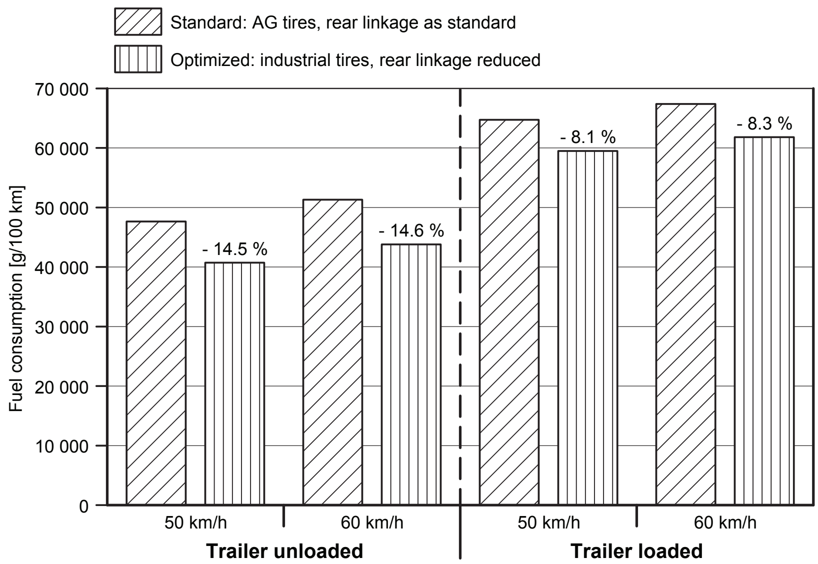

Figure 3: comparative presentation of fuel consumption of standard version and version optimized on road transportation

Across all trial variants the transport unit optimized on road transportation by industrial tires and weight reduction has a lower fuel consumption of 11.4 % on average. The saving is about 8 % with the trailer loaded. With respect to the higher payload of 2.4 % in the optimized versions the savings raise up to 10.3 % on average. In the variants with the trailer unloaded fuel savings finally end up to 14.6 %.

These dimensions are comparable to the results of Udompetaikul et al. (2011) and Reckleben et al. (2013). The superiority of the optimized concept mostly issues from higher inflation pressures of industrial tires. Thus the rolling resistance can be reduced significantly. It is remarkable that for both maximum speeds the advantage of the optimized versions is almost twice as high with empty trailer as with the trailer loaded. This fact is explainable by the distribution of the total weight between the different axles. With empty trailer approximately 50 % of the total weight of the transport unit press on the tractor axles being optimized. This proportion decreases to about 25 % after weighing the trailer at 40 tons. Thus, the optimization measures are no longer acting to the same extent as in the variants with empty trailer.

If the two versions ‚standard' and ‚optimized' are considered individually it is evident that – regardless of tire concepts and loading conditions – higher maximum speed (in this case 60 km/h) inevitably induces higher fuel consumption. The absolute fuel consumptions are comparable with results of previous studies (e.g. Götz 2011). Nevertheless they always have to be considered in relation to the driven test track which included 440 meters of altitude on a total length of 33.9 km in the present study.

In total, significant influences on the 5 % level were detected in the analysis of variance for maximum velocity (50 or 60 km/h) and optimization by tire changing and weight reduction.

Figure 4 shows average lap times as well as obtained average speeds for all eight variants. Again the values represent the average of three single measurements for each version. Concerning lap time the individual measured values vary about ± 4 % around the mean. In both versions (standard and optimized) the transport unit realized for both trailer loading conditions faster lap times at 60 km/h than at 50 km/h maximum speed. This difference is significant at the level of 5 %.

All speed values are to be seen against the background that the present study is an experiment under field conditions. The paces achieved depend on factors such as track condition (slopes, road quality, etc.), interaction with other road users or the proportion of in town and cross-town routes (Götz 2014).

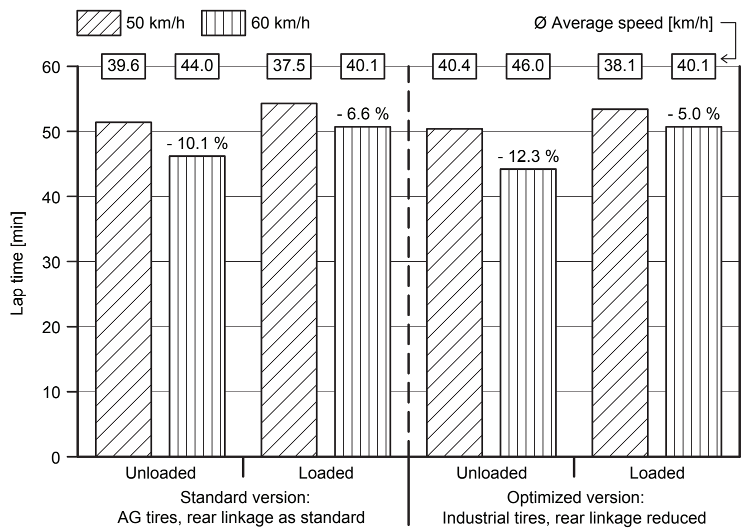

Figure 4: comparative presentation of lap times at maximum speeds 50 and 60 km/h

The shortest average time has been made in the optimized version with trailer unloaded and at a maximum speed of 60 km/h (44.2 min). In this case the lowest weight had to be moved. The transport unit could be accelerated very effectively and therefore it was best able to take advantage of route sections where 60 km/h are permitted. The standard version at 50 km/h maximum speed with the trailer loaded took the longest time (54.3 min).

Lower lap times at the maximum velocity of 60 km/h compared to 50 km/h result in higher average speed. These differences range from 2.0 km/h in the optimized version with the trailer loaded up to 5.6 km/h in the optimized version with empty trailer. Compared to the study of Götz (2011) which included a standard tractor of upper performance (243 kW) with 60 km/h maximum speed, the present values for average speeds are lower. The absolute difference of 3 km/h when the trailer is empty and 5.6 km/h with loaded trailer is caused by differing test courses and the lower engine power of the tractor used in the present study.

Concerning absolute lap times there is an average advantage of the unloaded variants amounting to 8.5 % compared to the versions with the trailer loaded; this range extends from 5.0 to 12.3 %. Again it is remarkable that time advantage comes out significantly higher for the trailer unloaded both in standard and optimized versions. The empty transport unit can be accelerated to the specific maximum speed easier. Therefore more time is available for effectively taking advantage of it. That effect is reinforced if only considering the test track's cross-country sections. For this the benefit amounts to an average of 9.8 %. In town this fact does not appear, because speed is limited to 50 km/h due to traffic regulations.

In contrast to the maximum speeds (50 or 60 km/h) the optimization of the transport unit by tire changing and weight reduction does not have any significant influence on lap times. However in terms of fuel consumption there is a significant advantage on the 5 % level in favor of the optimized versions.

Conclusions

Rising transport volumes and distances make alternatives and optimization measures increasingly useful and profitable. The substitution of standard AG tires by industrial tires is relatively easy to realize and enables considerably higher inflation pressures. In the present study the implemented optimization measures (tire change and dismounting of rear linkage) reduced fuel consumption by 11.4 % on average and increased payload by 2.4 %. Due to the different weight distribution on the axles of the transport unit the advantage of lower fuel consumption is considerably bigger in the versions with unloaded trailer (up to 14.6 %). In the versions with a gross vehicle weight of 40 tons the advantage is approximately 8 %. The remarkable extent of this benefit motivates to think about optimizing tractors with manageable effort which are priority used in road transportation. Besides lower fuel demand further reasons could be cited: less abrasion and enhanced durability of industrial tires (Reckleben et al. 2013) as well as increased payload by reducing weight.

For example, if doing the silo maize harvest or the application of organic substrates by single-phase logistics systems, it might be advisable to use a tire pressure regulation system due to frequent changes in field and road conditions. In this way the advantages of AG tires concerning traction performance especially in wet field conditions could be perfectly taken into consideration, while reducing fuel consumption and tire abrasion by higher inflation pressures in road transportation.

With regard to process efficiency the maximum permitted speed is an important factor for transport logistics. In terms of transport speeds tractors with 60 km/h maximum speed already are able to keep up with the performance of trucks, especially if the route does not include highways or motor roads. However, the costs of increased efficiency in the form of time savings by higher maximum speed have to be determined. When taking fuel consumption of the different variants into consideration, the 60 km/h versions achieve a time advantage of 8.5 % on average at a fuel consumption of 5.5 % higher. Again, this effect is more pronounced in the versions with empty trailer. The 60 km/h versions have to pay their time savings amounting to 10.1 % (standard AG tires) and 12.3 % (industrial tires) with a fuel demand of about 7 % higher.

For each single farm the decision of the appropriate alternative has to be made individually depending on farm- or even day-specific situations. It should be taken into consideration that due to traffic regulations 60 km/h tractors can only enforce their advantage cross-town and on roads of good conditions. The higher this share in the transport road, the more worthwhile is the higher maximum speed in terms of required transport time. Otherwise all consequences, such as higher fuel consumption or additional costs for the tractor's and trailer's registration and general inspection, have to be taken into account.

In conclusion on routes similar to the present test course a tractor with maximum speed of 60 km/h is definitely able to keep up with a truck concerning transportation velocity because trucks only take advantage of their higher speed options on highways and motor roads. Due to their significantly higher off-road capability tractors exhibit benefits when it becomes necessary to leave paved roads and to go into the fields.

References

AIC (2011): Automotive Information and Control Systems, AIC-6004 Swissline Uniflowmaster. Betriebsanleitung

Bernhardt, H. (2002): Schüttguttransport in landwirtschaftlichen Betrieben Deutschlands. Dissertation, Justus-Liebig-Universität Gießen

Bernhardt, H. (2014): Logistik. In: Frerichs, Ludger (Hrsg.): Jahrbuch Agrartechnik 2013. Braunschweig: Institut für mobile Maschinen und Nutzfahrzeuge, 2014. S. 1–9

Engelhardt, D. (2002): Transportfahrzeuge im Agrarbereich – Lastkraftwagen, Möglichkeiten und Konzepte, Cuvillier Verlag

Degrell, O.; T. Feuerstein (2003): „DLG-PowerMix" – Ein praxisorientierter Traktorentest. Tagungsband VDI/MEG Tagung Landtechnik Hannover 2003, VDI-Berichte Nr. 1798, S. 339–345

Fröba, N. (1994): Landwirtschaftliches Transportwesen. Landtechnik 49(6), S. 264–266

Götz, S. (2011): Agrarlogistik – Systemvergleich von Transportkonzepten der Getreidelogistik. Landtechnik 66(5), S. 381–386

Götz, S. (2014): Influencing factors on agricultural transports and their effect on energy consumption and average speed. Agric Eng Int: CIGR Journal, Special issue 2014: Agri-food and biomass supply chains, pp. 59–69

Herrmann, A.; Pickel, P.; Fröba, N. (2000): Transportgeschwindigkeiten von Traktoren. Auswirkung unterschiedlicher bauartbedingter Höchstgeschwindigkeiten. Landtechnik 55(5), S.338 ff.

Hörner, R. (2011): DLG Praxis-Monitor Ackerschlepperreifen: Mehr als nur Gummi in DLG Test Landwirtschaft, DLG Verlag, Frankfurt a. M.

Jílek, L.; Prazan, R.; Podpera, V.; Gerndtová, I. (2008): The effect of the tractor engine rated power on diesel fuel consumption during material transport. Res. Agr. Eng. 54(1), pp. 1–8

Kuratorium für Technik und Bauwesen in der Landwirtschaft (2013): Logistik rund um die Biogasanlage. KTBL-Schrift 498, KTBL, Darmstadt

Lindgren, M.; Hansson, P.-A. (2002): Effects of Engine Control Strategies and Transmission Characteristics on the Exhaust Gas Emissions from an Agricultural Tractor. Biosystems Engineering 83(1), pp. 55–65

Mührel, K. (1974): Landwirtschaftliche Transporte und Fördertechnik, VEB Verlag Technik, Berlin

Reckleben, Y.; Schäfer, N.; Weißbach, M. (2013): Steigerung der Effizienz bei Straßentransporten mit unterschiedlichen Reifentypen für Traktoren. Landtechnik 68(3), S. 196–201

Statistisches Bundesamt (2015): Güterverkehr 2014 in Deutschland. https://www.destatis.de/DE/PresseService/Presse/Pressemitteilungen/2015/02/PD15_050_463.html, accessed on 23 June 2015

Udompetaikul, V.; Upadhyaya, S.K.; Vannucci, B. (2011): The Effect of Tire Inflation Pressure on Fuel Consumption of an Agricultural Tractor Operating on Paved Roads. Transactions of the ASABE 54(1), pp. 25–30

Authors

M. Sc. Michael Mederle is member of the scientific staff and **Prof. Dr. Heinz Bernhardt** is Ordinarius and head of the chair of Agricultural Systems Engineering at the Technical University of Munich, Am Staudengarten 2, 85354 Freising-Weihenstephan, Germany, e-mail: michael.mederle@tum.de

B. Sc. Adrian Urban is studying Agrarmanagement at TUM.

Dipl.-Ing. (FH) Hubert Fischer is working at AGCO Marktoberdorf in the department of Product Marketing, which is headed by **Dipl.-Ing. (FH) Ulrich Hufnagel, MBA**.

Acknowledgement

The Chair of Agricultural Systems Engineering kindly thanks the AGCO Company in Marktoberdorf for providing the test machines, for the comprehensive technical support as well as for the excellent cooperation during the examination.