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Shifting performance in regular wear and tear

Chain shifting time 10-speed drive systems

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1. Introduction

The shifting behavior of bicycle chains produced by different manufacturers results in a strongly subjective judgment expressed by the user (mechanic, racing cyclist, hobby cyclist) as to the quality of the products. When shifting gears the user feels the reaction forces at the shifter, possible time differences between respective shifting processes as well as the ability to carry out the gear shifting process successfully even under load. Thus the judgment with respect to the quality of a shifting process remains a subjectively perceived criterion. Up to now a quantifiable statement regarding the shifting behavior (shifting performance) of a chain has not yet been scientifically documented. An objective comparison of shifting performances requires tests on a suitable test bench. Within the framework of the study described here the shifting performance of different chain systems is analyzed in order to be able to subsequently carry out a direct comparison.

2. Test objective

Test objective is the evaluation of the shifting performance of new 10-speed chains manufactured by Shimano, Campagnolo and SRAM in direct comparison to the reference products Connex 10s (new reference chain) and Connex 10sX as a reference chain with a run-in period of 1,000 km (tantamount to a wear increase of 0.07 %). On a suitable test bench shifting speeds (shifting time) between the 6th and the 7th sprocket are measured in order to assess the shifting performance of the chains objectively and quantifiably.

3. Chain test bench

In order to obtain a statement about chain performance which is as precise as possible, a test bench is required that is able to reflect the cycling and shifting behavior of a cyclist in a sufficiently exact manner. The bench used for these tests is shown in fig 1. Here the bicycle frame is fixed at the stem and via a support device at the bottom bracket; the chainstay can react elastically during a shifting process. Thus possible influencing factors caused by lateral chainstay elasticity as in real cycling are to be ensured.

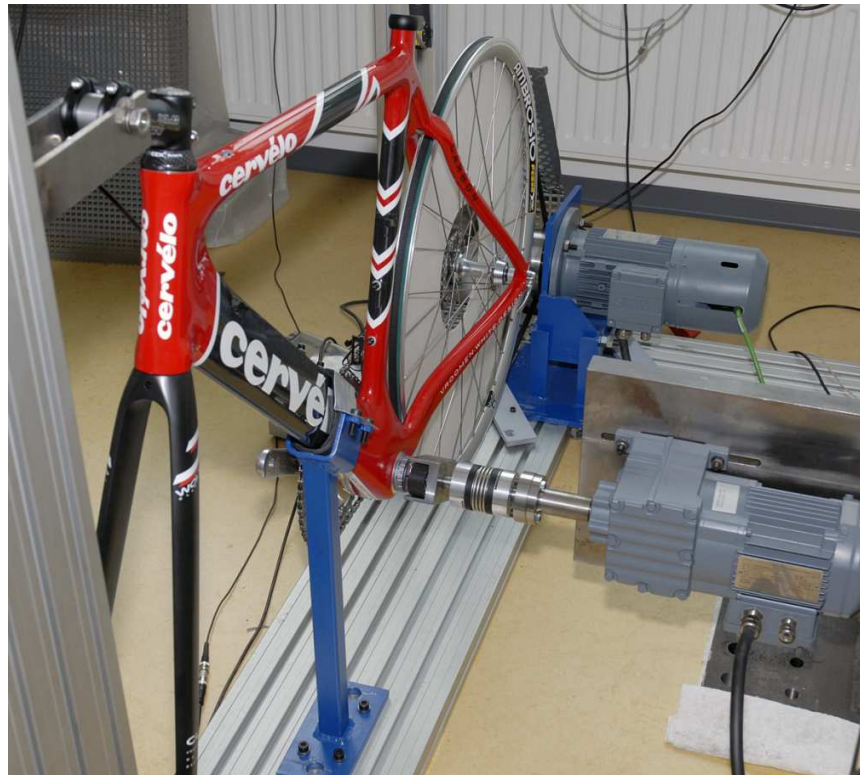


Fig. 1: Test bench to assess the shifting performance of 10-speed chains

The chain ring is driven by an asynchronous motor with an upstream gearbox (transmission ration $i = 55.76$) and a drive power of 0.25 kW. Between the motor and the foot pedal (type: Shimano Ultegra with 53 teeth) a metal bellow coupling is fitted in order to compensate misalignment as well as radial offset between drive and driven side (see fig. 2). The connection to the foot pedal is fork-shaped. It allows for an easy adaption of foot pedal sets by various manufacturers. The option to use different foot pedal sets is to remain.



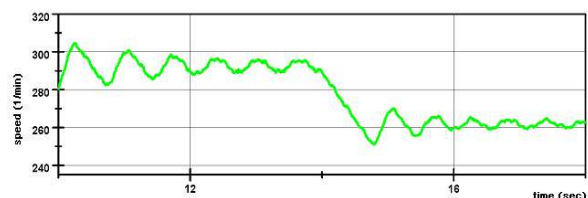
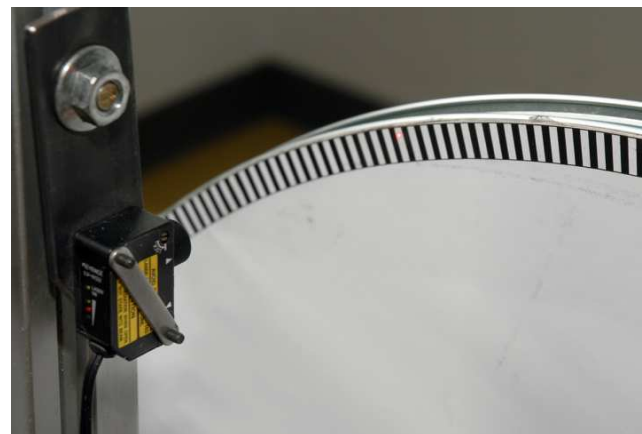
Fig. 2: Drive by means of connection assembly to foot pedal

The drive of the rear wheel (simulation of roll resistance and thus chain twisting) is realized during the tests by means of an asynchronous brake motor (0.75 kW), which is connected to the rear wheel by means of a flat belt drive. The elasticity of the belt drive is achieved via the dead weight of the brake motor, which is mounted eccentrically on a rotary axis. Due to the adjustable braking effect at the driven side with constant and also freely selectable drive / input speed the chain drive is loaded / twisted. The absolute amount of twisting cannot be ascertained with this type of test bench since there is no integrated torque gauge bar. The use of a respective torque measuring device has not been planned for these tests.

Rear wheel speed is measured by means of a laser pick up via an optical incremental measuring device (see fig. 3). For this purpose an accordingly printed disk was glued centrically onto the rim, which has a reflective tape pitch of 400 increments around its circumference. The sampling rate of the laser device is 10 kHz and the width of each unit on the tape is 2.5 mm.



Optical measuring device for speed measurement

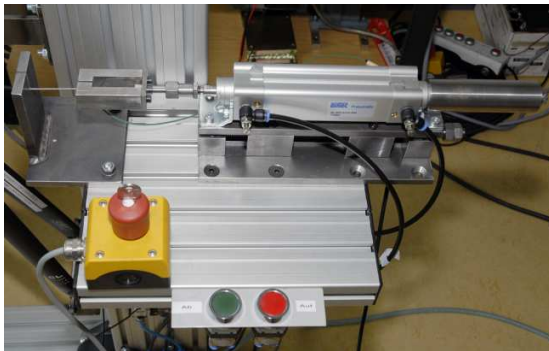


Detailed view: Laser beam on incremental disk and measuring record of speed signal

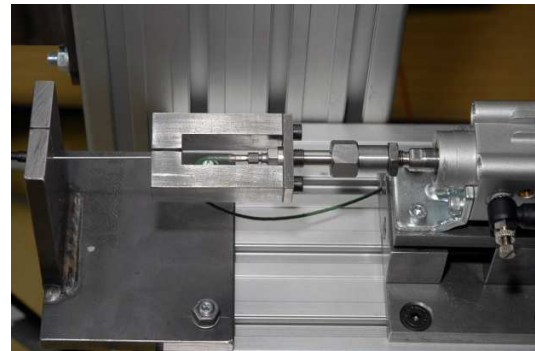
Fig. 3: Speed measurement by means of laser pick-up device

The input speed results from the number of teeth combination of the chain ring and the respective sprocket used. During the tests to quantify the shifting performance, the sprocket set as well as the chain ring remain the same for all chain types. The sprocket set is the product Dura-Ace CS-7800, 10-speed, made by Shimano with the grading 12-25 (this corresponds to 12-13-14-15-16-17-19-21-23-25 teeth). The input speed n of the foot pedal is a constant 90 min^{-1} in all test series. The shifting processes to be tested at the a.m. drive speed take place between the 6th and the 7th sprocket with 17 and 19 teeth respectively. Drive speed as well as sprockets used in the shifting process were initial requirements.

In order to achieve a high level of reproducibility of the measurements, the shifting process is carried out by means of a pneumatically operated circuit breaker (see fig. 4).



Pneumatic cylinder with force sensor



Detailed view of force sensor

Fig. 4: Pneumatically operated circuit breaker with integrated force sensor

The application of such a circuit breaker is necessary in order to eliminate user-specific differences whilst using the shifter (especially user-related differences as to shifting force and shifting speed). Thus absolutely reproducible and comparable shifting processes can be ensured.

The circuit breaker consists of a double-acting pneumatic cylinder (Airtec, type: HM-08-010), which is supplied with compressed air via a conventional compressor. By means of a suitable adjustment device the piston travel is adjustable in a way that shifting can be carried out neatly not only between two adjacent sprockets but also across several sprockets.

The piston of the pneumatic cylinder is directly connected to a Piezo force sensor (KISTLER, type: 9203). By means of a correspondingly shaped U-profile the connection of the force sensor to the gear cable is achieved. Piezo force sensors are especially suitable for force measurements in dynamic processes and are therefore suited for this kind of application. Triggering off the pneumatic cylinder prior to the tests is done manually by actuation of the respective control buttons (see fig. 4). Thus the shifting process can be started manually without, however, keeping constant time intervals between a series of several shifting processes. In the present test stand arrangement the shifting process is entirely automated. The shifting signal is preset by a function generator with a freely selectable timing cycle thus allowing for the compliance of shifting intervals with identical lengths. These preconditions render possible a direct comparison of shifting times with different chain types.

4. Measurements taken and evaluation

The chains to be tested all have the same lengths with 108 chain links and are in mint condition (new). This test series focuses on different chain types manufactured by Shimano, Campagnolo and SRAM (see tab. 1). Reference chains are the products Connex 10s and Connex 10sx. The shifting behavior of the reference chains is tested in mint condition (new) as well as with a run-in period of 1,000 km (tantamount to a wear increase of 0.07 %).

Manufacturer	Product type / additional information	
Shimano	Dura Ace CN-7801	Test chains (new, mint condition)
Shimano	Ultegra CN-6600	
Campagnolo	Veloce C10	
SRAM	PC1070	
SRAM	PC1090	
SRAM	PC1090R	
Wippermann	Connex 10s (new)	Reference chains
Wippermann	Connex 10sx (run-in period 1.000 km)	

Tab. 1: List of chains to be tested in comparison with the two reference chains

Two test series with a total of approximately 40 shifting processes (about 20 times upshifting and 20 times downshifting) are carried out with each chain in an unloaded state as well as under load. The respective signals for force and speed were recorded (see fig. 5). In this study the upshifting process is defined as a chain position change from the smaller sprocket (17 teeth) to the larger one (19 teeth).

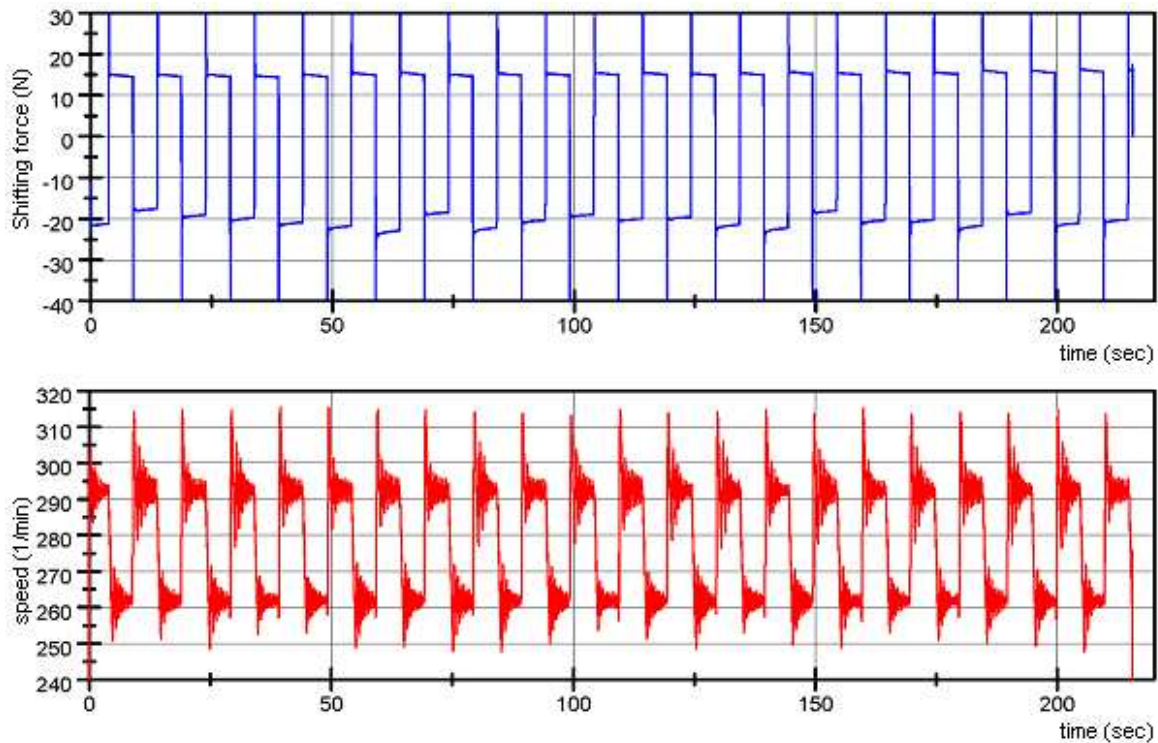


Fig. 5: Measuring record showing force and speed signals with a drive speed of 90 1/min and without chain pre-tension

Measuring signals are evaluated manually by means of the data analysis software DIAdem supplied by National Instruments. The first test series is carried out in an almost load-free condition. Pre-tensioning of the chains caused by the braking effect at the driven side is marginal, and merely belt elasticity due to the eccentric bearing of the output motor causes minimum pre-tensioning.

In these tests the first and the last five shifting processes out of the total of 40 recorded events are evaluated in each case. In the process two different times are evaluated: firstly, the time difference (interval numbered 1) between the beginning of the change of the force signal up to the beginning of the change of the speed signal is measured. Secondly, the time difference (interval numbered 2) between the beginning of the force signal up to the first minimum (maximum) of the speed signal is measured (see fig. 6). These time measurements are possible since both signals (force and speed) refer to the same time axis. Thus ten shifting times for upshifting and ten shifting times for downshifting are recorded for each chain type. Subsequently the average shifting time is calculated for each case. However, it must be pointed out here that the number of evaluated shifting processes for each chain is not sufficient for significant statistical results. With a number of sprocket teeth of 17 and 19 respectively at least 380 shifting processes per shifting direction (upshifting/downshifting) must be evaluated in order to be able to gather statistically verified results. Only then will there be a statistical guarantee that each tooth of the sprocket has been engaged in a shifting process in a sufficiently frequent manner (in case of the a.m. number of switching processes that would mean approx. 20 contacts per tooth). This is of particular importance since the individual tooth shapes of a sprocket vary considerably.

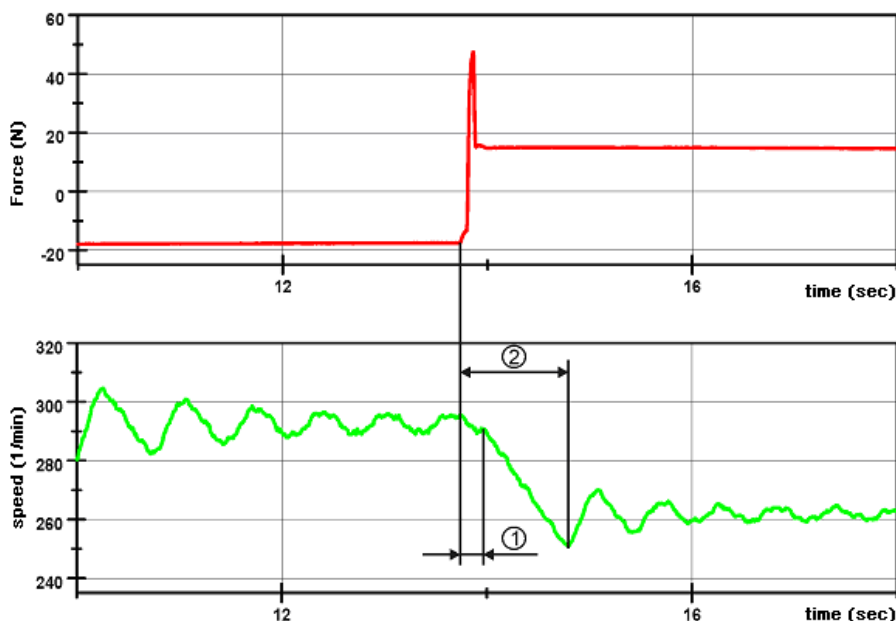


Fig. 6: Measuring record with evaluated time windows (interval 1 and 2) during upshifting

For the evaluation results see the following tables. They show the two time values as well as the respective position as to their shifting time.

Tab. 2 shows the averaged shifting times of both time measurements for upshifting from sprocket 6 to sprocket 7 with hardly any chain pre-tension. On the basis of shifting times shown in tab. 2 shifting time differences between the two reference chains and the competitors' products can be calculated (see tab. 3).

Type of chain	Time 1: Averaged time(s) of upshifting process <u>without</u> pre-tension	Time 2: Averaged time(s) of upshifting process <u>without</u> pre-tension	Position after evaluation of time window 1	Position after evaluation of time window 2
Wippermann Connex 10s (new)	0,2894	1,1463	3	3
Wippermann Connex 10sx (1.000 km)	0,3165	1,2375	8	8
SRAM PC1070	0,3045	1,1767	7	5
SRAM PC1090	0,2986	1,2140	6	7
SRAM PC1090 R	0,2953	1,1727	4	4
Campagnolo Veloce C10	0,2956	1,2086	5	6
Shimano Dura Ace CN-7801	0,2581	1,1157	1	2
Shimano Ultegra CN-6600	0,2738	1,1025	2	1

Tab. 2: Averaged shifting times (upshifting) from sprocket 6 to sprocket 7 without pre-tension

Green fields mark the times by which the Connex chains shift faster than those of the competitors. The other times are marked in orange.

Upshifting (without pre-tension)	SRAM PC1070		SRAM PC1090		SRAM PC1090 R		Campagnolo Veloce C10		Shimano CN-7801		Shimano CN-6600	
	Shifting times of the two Connex chains compared to the competitors' chains (in each case referring to the two evaluated time windows)											
	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]
Connex 10s (new)	+0,015	+0,030	+0,009	+0,068	+0,006	+0,026	+0,006	+0,062	-0,031	-0,031	-0,016	-0,044
Connex 10sX (1.000 km)	-0,012	-0,061	-0,018	-0,024	-0,021	-0,065	-0,021	-0,029	-0,058	-0,122	-0,043	-0,135

Tab. 3: Time differences of reference chains compared to competitors' products (upshifting, without pre-tension)

Tab. 4 shows the averaged shifting times of both time measurements for downshifting from sprocket 7 to sprocket 6 with hardly any chain pre-tension

Type of chain	Time 1: Averaged time(s) of downshifting process <u>without</u> pre-tension	Time 2: Averaged time(s) of downshifting process <u>without</u> pre-tension	Position after evaluation of time window 1	Position after evaluation of time window 2
Wippermann Connex 10s (new)	0,2323	0,5561	8	4
Wippermann Connex 10sx (1.000 km)	0,2157	0,5195	5	1
SRAM PC1070	0,2225	0,5829	6	7
SRAM PC1090	0,2138	0,5625	3	5
SRAM PC1090 R	0,2235	0,5759	7	6
Campagnolo Veloce C10	0,2149	0,5471	4	3
Shimano Dura Ace CN-7801	0,1882	0,5452	1	2
Shimano Ultegra CN-6600	0,2047	0,5857	2	8

Tab. 4: Averaged shifting times (downshifting) from sprocket 7 to sprocket 6 without pre-tension

Tab. 5 shows the comparison of the respective shifting time differences.

Downshifting (without pre-tension)	SRAM PC1070		SRAM PC1090		SRAM PC1090 R		Campagnolo Veloce C10		Shimano CN-7801		Shimano CN-6600	
	Shifting times of the two Connex chains compared to the competitors' chains (in each case referring to the two evaluated time windows)											
	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]
Connex 10s (new)	-0,01	+0,027	-0,019	+0,006	-0,009	+0,02	-0,017	-0,009	-0,044	-0,011	-0,028	+0,03
Connex 10sx (1.000 km)	+0,007	+0,063	-0,002	+0,043	+0,008	+0,056	-0,001	+0,028	-0,028	+0,026	-0,011	-0,066

Tab. 5: Time differences of reference chains compared to competitors' products (downshifting, without pre-tension)

Tab. 6 shows the averaged shifting times of both time measurements for upshifting from sprocket 6 to sprocket 7 with maximum pre-tension

Type of chain	Time 1: Averaged time(s) of upshifting process <u>with</u> pre-tension	Time 2: Averaged time(s) of upshifting process <u>with</u> pre-tension	Position after evaluation of time window 1	Position after evaluation of time window 2
Wippermann Connex 10s (new)	0,2788	0,6833	7	7
Wippermann Connex 10sX (1.000 km)	0,3359	0,7357	8	8
SRAM PC1070	0,2591	0,6420	2	2
SRAM PC1090	0,2507	0,6352	1	1
SRAM PC1090 R	0,2645	0,6511	4	5
Campagnolo Veloce C10	0,2696	0,6509	5	4
Shimano Dura Ace CN-7801	0,2626	0,6448	3	3
Shimano Ultegra CN-6600	0,2727	0,6628	6	6

Tab. 6: Averaged shifting times (upshifting) from sprocket 6 to sprocket 7 with pre-tension

Tab. 7 shows the comparison of the respective shifting time differences.

Upshifting (with maximum pre-tension)	SRAM PC1070		SRAM PC1090		SRAM PC1090 R		Campagnolo Veloce C10		Shimano CN-7801		Shimano CN-6600	
	Shifting times of the two Connex chains compared to the competitors' chains (in each case referring to the two evaluated time windows)											
	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]
Connex 10s (new)	-0,02	-0,041	-0,028	-0,048	-0,014	-0,032	-0,009	-0,032	-0,016	-0,039	-0,006	-0,021
Connex 10sx (1.000 km)	-0,077	-0,094	-0,085	-0,101	-0,071	-0,085	-0,066	-0,085	-0,073	-0,091	-0,063	-0,073

Tab. 7: Time differences of reference chains compared to competitors' products (upshifting, with maximum pre-tension)

Tab. 8 shows the averaged shifting times of both time measurements for downshifting from sprocket 7 to sprocket 6 with maximum pre-tension

Type of chain	Time 1: Averaged time(s) of downshifting process <u>with</u> pre- tension	Time 2: Averaged time(s) of downshifting process <u>with</u> pre- tension	Position after evaluation of time window 1	Position after evaluation of time window 2
Wippermann Connex 10s (new)	0,1865	0,6286	2	2
Wippermann Connex 10sx (1.000 km)	0,2054	0,6400	8	5
SRAM PC1070	0,1876	0,6319	4	3
SRAM PC1090	0,1796	0,6353	1	4
SRAM PC1090 R	0,1874	0,6418	3	6
Campagnolo Veloce C10	0,1923	0,5998	5	1
Shimano Dura Ace CN-7801	0,2000	0,6683	7	8
Shimano Ultegra CN-6600	0,1961	0,6497	6	7

Tab. 8: Averaged shifting times (downshifting) from sprocket 7 to sprocket 6 with pre-tension

Tab. 9 shows the comparison of the respective shifting time differences.

Downshifting (with maximum pre-tension)	SRAM PC1070		SRAM PC1090		SRAM PC1090 R		Campagnolo Veloce C10		Shimano CN-7801		Shimano CN-6600	
	Shifting times of the two Connex chains compared to the competitors' chains (in each case referring to the two evaluated time windows)											
	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]	Time 1 [s]	Time 2 [s]
Connex 10s (new)	+0,001	+0,003	-0,007	+0,007	+0,001	+0,013	+0,006	-0,029	+0,014	+0,04	+0,01	+0,021
Connex 10sX (1.000 km)	-0,018	-0,008	-0,026	-0,005	-0,018	+0,002	-0,013	-0,04	-0,005	+0,028	-0,009	+0,01

Tab. 9: Time differences of reference chains compared to competitors' products (downshifting, with maximum pre-tension)

In summary fig. 7 shows the measured shifting times (shifting times 1 and 2) listed in tables 2, 4, 6 and 8 for the upshifting process with and without pre-tension.

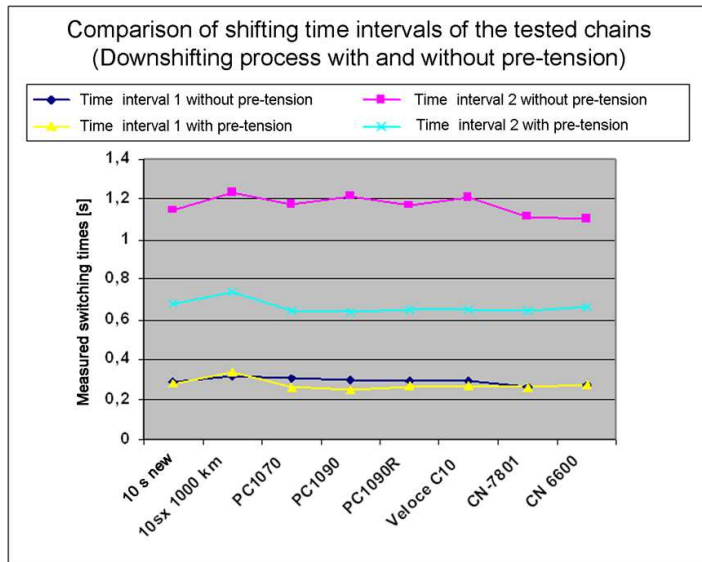


Fig. 7: Comparison of shifting times (shifting times 1 and 2) during upshifting with and without pre-tension

Correspondingly, fig. 8 shows the shifting times for the downshifting process (with and without pre-tension).

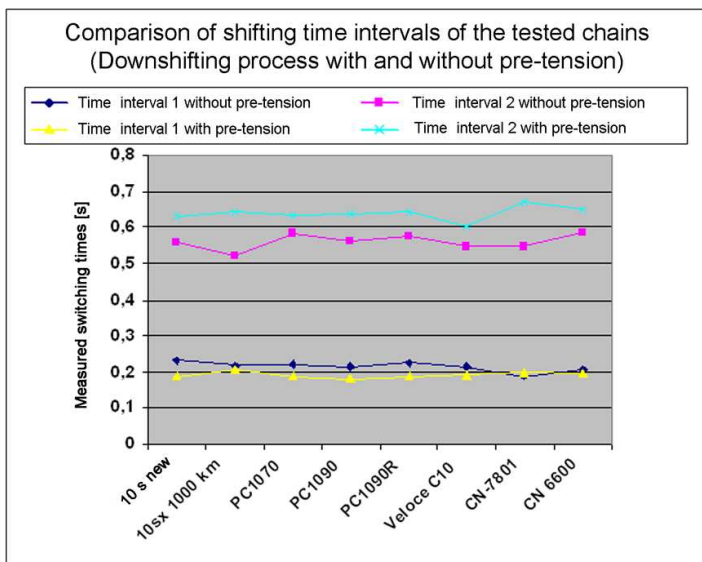


Fig. 8: Comparison of shifting times (shifting times 1 and 2) during downshifting with and without pre-tension

The test results show a slight tendency that the Connex chains seem to shift more slowly than the competitors' products. However, quantitative statements as to the shifting performance of the individual chain types may not be deduced from the results. The shifting time differences are too marginal to allow significant conclusions. Furthermore, more importance should be attached to the upshifting process with or without pre-tension than to downshifting since the former is a well-defined process (contrary to downshifting) where the chain and the tooth shape of the sprocket contribute essentially to the position change. In most cases the Connex chains perform worse than their competitors during upshifting; this applies to the new chains as well as to the run-in ones. It remains to be seen if these results will hold up in further tests.

The influence of the Shimano Ultegra foot pedal fittings on the shifting performance of chains produced by different manufacturers was not tested. Moreover, an analysis of the influence of the sprocket set (manufacturer, type and teeth geometry) was not carried out, either. The question in how far the tooth shapes of different component manufacturers differ cannot be answered here.

Within the framework of this study only new chains produced by competitors were tested. The influencing factors of wear and tear on general shifting behavior of chains were not tested.

The question if the results at hand suffice in order to evoke a certain sensation so that the cyclist feels one chain has a "better" or a "worse" shifting behavior than another one also remains unanswered.

5. Summary

In order to be able to make quantitative statements as to the shifting performance of chains in 10-speed drive systems a bicycle chain test bench was assembled. A pneumatically operated circuit breaker was developed, which eliminates user-specific shifting characteristics as well as subjective sensations and perceptions while operating the shifter. Furthermore, switching intervals of identical lengths could be realized by means of a function generator. This is a basic condition for an objective comparability of the respective shifting processes.

By means of a suitable coupling between drive and driven motor switching tests could be carried out with almost load-free and pre-tensioned chains. During the tests the shifting force and the speed at the driven side with given drive speeds were measured.

The evaluation of averaged shifting times did not result in quantitative statements on the shifting performance of individual chains. The time differences between the tested chains are only marginal.

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