After a few years development, a website called ALL-ABOUT–HUBS, with much information and many links, suddenly disappeared. It re-appeared again as a PDF-file in the V-CC archives. I assume the makers stopped their project and tried to save some of their work, by passing it on to the archives of the V-CC in pdf-format. Alas a lot of information was lost and links were no longer valid.

This is an effort to access some of the knowledge from the site and pass that on to the reader. It is an extract of the original file that can be found at the end of the page :

NCA and Public Library, at https://v-cc.org.uk/about/library/

Planetary gears (1898-2012)

Introduction

A shift gearbox enables the rider to move at different speeds though pedalling constantly. According to the rules of physics you gain more torque with speed - reducing ratios and you loose torque with speed - increasing ratios. Thus we can ride up a hill conveniently without breaking to sweat - but we need more time and if we are in a hurry we can gear up - but then we don't have that much torque for accelerating or riding up a hill. What is commonly known as gear, consists of 3 gear components, because it has an input shaft, an output shaft and - not forgetting - a housing as the third gear element - which is of course not rotating. It is similar with a hub as a whole, but the gear shafts are arranged a little bit unusual - more figuratively: The sprocket presents the input shaft, the hubs shell displays the output shaft and the third component is the hub axle, which is fixed non-rotating in the bike frame.

Components of geared hubs.

Simple planetary gear train.

Planetary gears were not invented by space research, but it got its name from the arrangement of the gear components like a planetary system: Several planet wheels (named also 'planets') placed in a cage called planet carrier (also named 'arm') revolve around a central sun gear ('sun'). The planets itself mesh with the sun gear and a ring gear. These three gear components form a simple planetary gear train with three gear shafts. A planetary gear train can be operated in two configurations, you can find both of them in geared hubs: In a dual shaft gear one of the gear shafts is fixed thus presenting the housing / support.

Planet carrier and sun within Sachs H3111

Planet carrier of Sachs orbit

One of the two remaining gear shafts can be defined as input shaft, the other shaft then works as output shaft. This configuration is installed in most of the geared hubs. In a triple shaft gear all shafts are revolving which gives you the choice to drive two shafts and get one output shaft (summation gear) or to drive one shaft and receive two shafts as output (power divider). Some geared hubs also contain this gear configuration (summation gear) in which the 'housing' is formed by the axle as the fourth gear component being fixed.

Simple planetary gear trains (dual shaft gear)

In a simple planetary gear train configured as dual shaft gear one of the gear shafts is fixed thus presenting the housing / support. The gear ratio depends on the gear component which is the fixed part. The sun always meshes with the planets which transfer the torque collectively to the ring gear. A planetary gear allows to transfer much more torque compared with a standard spur gearing of the same size, since several gears always mesh with each other. Most planetary gear trains in geared hubs contain 3 or 4 planets. The stationary gear ratio i12 is the ratio between the numbers of teeth of the ring gear to the teeth of the sun gear.

Stationary planet carrier

In this configuration sun and ring gear are the rotation components whereas the planet carrier forms the stationary part. This is a so called stationary gear - principally a normal spur gearing with all components just rotating around their own axis but nonrevolving. Sun and ring gear have different rotation directions and the gear ratio is i12. This configuration is not applied in hubs due to the different rotation directions, but you will sometimes find it in some industrial planetary gears or in automatic transmissions in cars or buses in which the reverse gear is implemented in that way.

Stationary planet carrier

Stationary ring gear

Stationary sun

Stationary ring gear

In this configuration sun and planet carrier are the rotation components whereas the ring gear forms the stationary part. It is a so called epicyclic gear, since the planet carrier is rotating and the planets revolve around the sun. This configurations allows even higher ratios than the stationary gear (i12+1) and can be found in most of the industrial planetary gears. It is very rarely applied in hubs, since you will need finely graded ratios in bikes - but you will find it in a cordless screwdriver. The Rohloff Speedhub contains a planetary gear train with fixable ring gear.

Stationary sun

In this configuration planet carrier and ring gear are the rotation components whereas the sun gear forms the stationary part - it can be fixed with the shaft. This is an epicyclic gear as well, but only small transmission gear ratios are achievable - that's why this configuration is ideal for geared hubs. Driving the planet carrier leads to a speed increasing ratio with the factor 1+ (1/i12), always being between >1 and 0,5. Sentence to remember for this configuration: The bigger the ring gear compared to the sun (leading to a bigger ratio i12), the closer is the ratio of this gear train. A second sentence to remember for this configuration affects the rotation speed of planet carrier and ring gear: The ring gear always rotates faster than the planet carrier

Planet carrier with internal teeth for coupling with sun

Fixable sun within Sachs doubletorpedo

Direct gear

It is also possible to join two gear components together thus achieving a direct gear where the ratio is skipped leading to i=1:1. Coupling e.g. sun and planet carrier - the sun must remain revolvable - leads the ring gear to rotate with the same speed than the planet carrier. Some antique hubs (e.g. Fichtel & Sachs Doppeltorpedo) have applied a direct gear in that way.

Deactivated gear

In some hubs it may also be the case that the planet carrier is driven and the sun is pivoted - actually two unfixed components exist. The ring gear (as output member) will revolve slightly due to inner friction at first, but it is not able to transfer any torque. You could prevent the ring from turning and the sun gear would start to rotate then. In this way the output component of a gear train is deactivated and another gear train can get operative (applied e.g. in Shimano Nexus Inter 7).

Stepped planetary gear trains

A simple planetary gear train provides 3 speeds when operated as epicyclic gear with stationary sun: A hill gear, a direct gear and a fast gear. If you want to achieve closer gear ratios, then - according to the first sentence to remember - the ring gear must be enlarged, but this would increase the hub considerably in diameter. Alternatively you could combine a second planetary gear train trying to achieve the desired overall gear ration, but this would increase the intricacy of the hub. A stepped planetary gear train allows to achieve closer or wider ratios within one gear train:

Non shiftable stepped planetary gear trains

A small sun gear meshes with the bigger wheel of a staged gear wheel (stepped planet) and the smaller wheel of the stepped planet meshes with the ring gear (in normal size). This can be compared with two cascaded reduction stages leading to an increasing of the stationary gear ratio i12. Stepped planetary gear train with one sun only are applied in some antique hubs (e.g. Sturmey-Archer Model 'AM'), as well as in contemporary hubs (e.g. Shimano Nexus Inter 8).

Non shiftable gear train

Shiftable stepped gear train

Shiftable stepped planetary gear trains

A shiftable stepped planetary gear trains also contains stepped planets as described before, but every wheel of a stepped planet meshes with a corresponding sun gear, which can be selectively fixed or rotatable on the axle unit. All stepped planets are situated in a common carrier and there is only one ring gear, which could be at any position - but is mostly placed around the medium-sized sun /planet. Fixing one sun at one time result in different stationary gear ratios - the other suns must remain pivotable and fulfil a compensation movement only. With dual staged planet you receive an additional hill gear and - operating the gear also reverse - an additional fast gear, resulting in 5 speeds all in all. Stepped planetary gear trains are pretty common in geared hubs, e.g. the SRAM 'Spectro S7' model contains only one shiftable stepped planetary gear train which allows 7 speeds thus gaining a good price-performing ratio due to the relatively simple gear structure. The more stages a stepped planet has, the longer it gets - and the planet cage as well - which leads to awkward balance of forces. That's why a triple stepped planetary gear train is the highest of emotions of what you will find within hubs.

Planet carrier2 with attached sun1 of planetary gear train1

Planetary gear train1 with sun1 driven by planet carrier2

Differential planetary gear trains

As already mentioned at the beginning it is also possible to operate a planetary gear train as triple shaft gear. Some hubs contain a differential planetary gear train as summation gear, i.e. two gear components are driven and the output member revolves with the superposition of both initial speeds. This allows to get additional individual gear rations - similar to the stepped planetary gear train. In hubs with a differential planetary gear train always the planet carrier or the ring gear is the output member, never the sun. The speed of the ring gear as output member is the superposition of the single ring gear speeds which would perform when only the sun was driven (fixed ring gear) or only the planetary carrier was driven (fixed sun). The speed of the planet carrier as output member is the superposition of the single planet carrier speeds which would perform when only the sun was driven (fixed ring gear) or only the ring gear was driven (fixed sun). So let's run through both these possibilities when planetary carrier or ring gear are driven with constant speed and the sun with more and more speed.

Ring gear as output member

Sun does not rotate: This presents an epicyclic gear with small ratio, the ring gear rotating faster than the planet carrier (small speed increasing ratio). Sun rotates slower than the planet carrier: A driven sun causes the ring gear rotating 'relatively' against the sun - like in the stationary gear, i.e. the ring gear will rotate slower (even smaller speed increasing ratio). Sun rotates at same speed with planet carrier: Both components ca be viewed as linked together achieving a direct gear (1:1 ratio).

The ring gear (outside) and the planet carrier (inside) can both serve as output member

Sun rotates faster than planet carrier: The ring gear rotates reverse faster more and more referred to the planet carrier (stationary gear) thus leading to a progressively reducing ring gear speed (speed reducing ratio). Sun rotating i12 - times faster than the planet carrier: The ring gear rotates backward - caused by the sun rotation - as fast as it rotates forward - caused by the planet carrier. The resulting ring gear speed gets zero (output standing still).

Sun rotates faster than before: The ring gear rotates backward faster than it driven forward. The resulting ring gear speed gets negative (output rotating backward). Planet carrier as output member Sun does not rotate: This presents an epicyclic gear with small ratio, the planet carrier rotating slower than the ring gear (close speed reducing ratio). Sun rotates slower than the ring gear: A driven sun causes the planet carrier rotating in sun direction - like in the epicyclic gear with large gear ratio, i.e. the planet carrier will rotate faster (even closer speed reducing ratio).

Sun rotates at Planet carrier2 with attached sun1 of planetary gear train1 Planetary gear train1 with sun1 driven by planet carrier2 same speed with ring gear: Both components ca be viewed as linked together achieving a direct gear (1:1 ratio). Sun rotates faster than ring gear: The planet carrier will rotate faster more and more - by the sun rotation - and both driving speeds will add up. The resulting planet carrier speed will get more and more faster compared to the ring gear (now speed increasing ratio).

Features of the differential planetary gear trains As you can see, the gear ratio in these configurations depends on the factor i12 AND on revolution speed of the driven elements. Both configurations allow speed increasing and speed reducing ratios without having to revert the power transmission (like in the dual shaft gear). With the ring gear as output member it would even be possible to cause the output member standing still or driving reverse. The possibility to design the gear ratios freely make this operation mode very interesting for hubs, but it make hubs with differential planetary gear train also more complex: Since you have at least to drive one input member with variable speed you will need one addition planetary gear train. Among the hubs containing a differential planetary gear train is the SRAM I motion 9 as contemporary hub and also some antiques hubs like the SACHS Elan or some Sturmey-Archer 3 or 4 speed hubs.

Hub elements

Introduction

This chapter presents specific hub elements which can also be found - in different design - in many other hubs. There are some elements to be comprised in every geared hub, e.g. at least 1 planetary gear train, a hub shell, etc. but there are also elements which are not built-in everywhere, e.g. a driver, a coaster brake, etc. Not every potential hub elements are described, but the elements of the Sram Spectro P5 are choosen as an exemplar of a contemporary hub frequently to be found. Similar elements can be implemented very differently in other hubs.

Sram Spectro P5

Internal gearing

Components

Sprocket

Most of the hubs contain a sprocket as drive member but there are also constructions with pulley for a belt drive to be found. Moreover you'll find combinations, which - similar to a racing bike - use a gear rim instead of a single sprocket. The sprocket is driven by chain from the pedal wheel and it has mostly between 16 and 24 teeth, the Spectro P5 has oftentimes 21 teeth. Contemporary sprockets matching for most of the hubs are designed identical at its bore diameter (dimension about 35mm) comprising 3 lugs meshing with 3 corresponding grooves of the drive member when joined to it thus transmitting the torque. They are locked by circlip and washer. In some historic hubs the sprockets have a female thread and are screwed on, others have an internal toothing and are locked by a nut. There also exist some hubs with significantly bigger sprockets due to its larger designed shifting unit. The sprocket of the Fichtel & Sachs Elan has 26 teeth with an inner diameter of 80mm.

Sprocket

Sprocket on driver

Sprocket of Sachs Elan.

Driver

In some hubs the sprocket is placed directly on a gear component (e.g. in the Sturmey-Archer X-8RF8 this is the planet carrier of the first gear train). Various hubs contain a driver holding the sprocket and distributing the power flow to the different gear components by a clutch. In the Spectro P5 the driver is a bushing with internal splines including a sliding clutch (radiating clutch). This clutch can be joined selectively with the planet carrier or the ring gear. In the range of the sprocket the driver contains the grooves as mentioned before, apart from that it contains 2 bearing seats: With an internal ball ring it is supported on a fixed bearing cone of the hub axle and with an external ball ring the hub shell is supported on it. Various hubs contain a driver designed in this way. In some hubs the driver contains internal pawls meshing with a gear component which can be deactivated by a cam plate or similar (e.g. Shimano Nexus Inter 7). Some hubs also contain a driver with both forward directed and backward directed pair of pawls meshing with a toothing within the ring gear which can be deactivated in pairs. The backward directed pawls cause high braking force when backpedaling. Many historic Sturmey-Archer hubs contain a claw-like driver with radiating clutch.

With radiating clutch

Sturmey-Archer driver

Driver Nexus Inter7

Bearing

The hub shell is ball bearing mounted in all hubs both on the drive side and the brake side, additionally a ball bearing is integrated in the drive member. The Spectro P5 - like most of the other hubs as well - doesn't contain standard ball bearings but ball rings revolving between bearing seats. Thus the driver contains a small bearing seat and a small ball ring revolving on the seat of the fixed bearing cone. A large ball ring placed on the second bearing seat of the driver supports the drive side of the hub shell. Finally there is a third, medium-sized ball ring placed between the bearing seat of the brake arm and the brake side seat of shell. All other gear elements are mostly not ball bearing mounted but run within oil or grease - apart from some special hubs with needle bearings within the gearwheels (e.g. Rohloff Speedhub). Some historic hubs contain additional bearings, e.g., the Fichtel & Sachs Model 29 has a built-in needle roller and cage assembly between the planet carrier and the drive cone. In Sturmey-Archer hubs the ball ring within a bearing ring is always screwed in the hub shell on the sprocket side.

Ballrings

Thrust bearing Sachs model 29

Ball ring S. A. AW

Axle

The axle of a hub presents the 'base frame' of the gearing and it is always screwed non-rotatable to the bike frame. In simple hubs the sun gear is firmly mounted to the axle or sun and axle are produced from one part. The Spectro P5 contains a dual stepped planetary gear train, i.e. 2 suns rotate on the axle with one sun being freely rotatable and the other one being fixed. In many hubs the axle contains some components of the clutches in order to connect the different gear members with each other. The Spectro P5 has a hollow drilled axle including two indexing pins, springs and sliding blocks which protrude from two elongated holes bothsided. Via the sliding blocks the sun gears get fixed or released and a radiating clutch gets moved within the driver. The axle has a small toothing for fixing the sun gears when they mesh with it. This pretty simple design is implemented in various hubs.

In some other hubs the sun gears get fixed in another way, e.g. by a shift drum situated around the axle, to be found within the Shimano Nexus Inter 7 or Inter 4. In that case the axle has small cams in the area of the suns and combined with the shift drum this allows specific sun gears to be fixed or released at specific rotation angles. This can be called an axle unit, because some components of the internal clutch are already integrated in the axle and a cam plate, springs, etc. which regulates the external clutch. The axle unit of the Shimano Nexus Inter 8 is even more complex, since the axle contains small extendible pawls.

Axle elements

Shifting unit

Axle unit Nexus7

Planetary gear train

A planetary gear train is the heart of every geared hub, in the Spectro P5 it is a single stepped planetary gear train providing two hill gears (speed reducing ratio when the ring gear is driven), two fast gears (speed increasing ratio when the planet carrier is driven) and one direct gear. The ring gear has a short toothing in its rear area which allows it to be coupled with the radiating clutch. Various Sturmey-Archer hubs share the same design but they have an internal wedge profile instead. Furthermore, pawls can be seen meshing with a corresponding toothing within the hub shell (freewheel). Ring gears as input member AND output member (with pawls) are often to be found in geared hubs. The pawls are often implemented with a spring ring in Fichtel & Sachs hubs. In Sturmey-Archer hubs, however, contain bigger pawls rotatably mounted in a pin.

The planet carrier comprises stepped planets supported on both sides, because an axle mounted on one side would bend too much. Some hubs also contain planet wheels mounted on one side, but only with simple gear trains. The planet carrier merges into the brake screw which is needed for the coaster brake version. The 2 staged planets are produced from one part, some hubs containing triple stepped planets use 2 pluggable parts. In some historic hubs the planet carrier also contains an internal toothing in which the sun gear could be inserted for achieving a direct gear. Planet carriers as input member AND output member (with pawls) are often to be found in geared hubs as well. In the Spectro P5 the pawls of the planet carrier are installed in the braking cone which co-rotates with the planet carrier. In many Sturmey-Archer hubs the planet carriers have directly installed pawls - similar to the ring gear - since often there's no coaster brake. There are several grooves in the suns which can be moved by the sliding block in a way that one sun remains rotatable or gets fixed within the axle toothing. This principle - to insert a sun with internal toothing to an external toothing of the axle - can be found in various hubs. But there are also other interesting principles - if hubs are not shifted with a rotary shifter instead of a toggle chain: The sun gears of the Nexus Inter 4 or Inter 7 e.g. have small internal pawls revolving around a shift drum. Depending on the rotation angle of the drum the pawls climb over the cams of shaft and drum (sun released) or they get locked (fixed sun).

Ring gear

Stepped gear train.

Sun gears

External clutch

Let's define external clutches as clutches which join gear members within a gear train to gear members outside the gear train. In the Spectro P5 this is the radiating clutch which can be moved within the driver in order to get connected with the planet carrier or the ring gear. The driver is internally splined in order to transfer torque, allowing to transfer the rotation of the sprocket to the radiating clutch. The clutch can mesh with the planet carrier by its radiating outline and allows meshing its small toothing to mesh with the toothing of the ring gear. The radiating clutch can be moved by pressing the external indexing pin (pipe) against a sliding block which moves a spring loaded ring towards the clutch. The external clutch allows selecting between hill gear, direct gear and fast gear and the internal clutch allows selecting within two hill gears or two fast gears by fixing the corresponding suns.
Fast gears: The external indexing pin is pushed in completely and the radiating clutch is joined to the jaws of the planet carrier with its radiating outline. The ring gear is the output and drives the hub shell by its pawls. The pawls of the planet carrier rotate as well but the get 'overtaken' by the toothing within the hub shell, thus hey cannot transfer any torque and you can hear the distinctive fast 'klacking'.

Direct gear: The external indexing pin is pushed in mid-position causing the radiating clutch to release the planet carrier and connecting the clutch with the toothing inside the ring gear. The pawls of the ring gear now revolve the hub shell as fast as it is driven by the driver, the gear train is bypassed and the pawls of the planet carrier is overtaken as well without transferring any torque. The klacking gets slower.

Hill gears: The external indexing pin is not pushed, the radiating clutch is pushed to the sprocket side by a spring thus also pushing the ring gear. The pawls of the ring gear get disengaged with the toothing of the hub shell and cannot transfer any torque any more. Now the ring gear is driven and the slower rotating planet carrier is the output, i.e. the hub shell is driven by the pawls of the brake cone in the toothing of the brake side. A lot of hubs with 3, 5, or 7 speeds work that way, containing a similar designed external clutch. The planetary gear train is driven in both directions (bidirectional), with speed increasing ratio AND with speed reducing ratio when the reversing the power flow. Some hubs work without an external clutch, e.g. the Shimano Nexus Inter 4only contains internal clutches for the sun gears, and there is only a speed increasing ratio (unidirectional power flow). In many Fichtel & Sachs hubs the radiating clutch pulls the ring gear with its pawls out of the toothing of the shell thus achieving the hill gear. In Sturmey-Archer hubs, however, the pawls of the ring gear are deactivated when the radiating clutch presses them radially inwards out of the toothing of the shell.

Shifting

Clutch Nexus Inter3

Internal clutch

Let's define internal clutches as clutches which join gear members within a gear train to gear members within the same train, e.g. sun gear to the axle. In the Spectro P5 this is a sliding block to be actuated with the internal indexing pin in order to move sun gears against spring force. The displaced sun gets engaged with the axle toothing by its internal notches and thus it is fixed. In the stepped planetary gear train you achieve a new stationary gear ratio i12 which provides 2 different speed increasing and 2 different speed reducing gear ratios instead of 1.The different manufacturers have found some more interesting conceptual designs in order to fix or to release suns: E.g., in the Shimano Nexus Inter 7 you will find pawls within the sun gears which climb over the cams of the axle or get locked depending of the rotation angle of the shift drum. The Shimano Nexus Inter 8 uses the inverted principle: The sun gears are internally splined and revolve around controllable pawls situated on the axle.

In the Sachs Elan slewable cam rods are installed in a notched axle instead of a shift drum thus causing the pawls of the suns either to climb over the notches (sun released) or to get locked against the bars of the axle (sun fixed).

Cam rods Elan Sun Nexus7 Shifting

Power transmission

A lot of hubs have two transmission outputs - as already mentioned in chapter External clutch - some have only one output, but all outputs are always joined with the hub shell. To prevent the pedals from rotating permanently the power transmission to the hub shell is mostly provided by 'free-wheels'. These clutches only allow transferring the torque in one direction. If the drive member rotates slower than the hub shell - i.e. the feet rest on the pedals or you pedal backward - the drive member is decoupled. The output (hub shell) can 'overrun' the input, that's why these elements are also called 'overrunning clutches'. There are some geared hubs without freewheels causing the pedals to rotate permanently, so-called 'Fixed gear' hubs, among them the historic Sturmey-Archer Model 'ASC', which is highly desired among the collectors. The Spectro P5 has pawls attached at the ring gear and at the brake cone which is driven by the planet carrier, accordingly the hub shell has two internal toothings fitting to the pawls. There are also hubs with only one output, e.g. the Sturmey-Archer X-8F8(W) has only one transmission output and therefor only one internal toothing within the shell. Some hubs have rollerramp clutches instead of pawls, small rollers are pressed radially outwards by an adequate profiled ring and drive on the unprofiled shell completely soundless. These rollerramp clutches are used in the Sachs Doppeltorpedo or the Shimano Nexus Inter 8. Some historic hubs, e.g. Sachs Model 29 also use a drive cone being pulled into a cone ring by a worm gear and thus driving the hub shell via the cone ring. This design is also completely soundless. A characteristic feature of Sturmey hubs is the screwed in ball ring at the driver side which also contains the internal toothing for the pawls of the ring gear.

Pawls ring gear Drive cone Rollerramp clutch.

Coaster brake

The Spectro P5 contains a coaster brake according to the 'brake screw' design to be very often in coaster brake hubs: The planet carrier has an attached worm gear carrying a brake cone with pawls. The brake cone screws toward the planet carrier, gets revolved and transfers torque to the hub shell when pedaling in driving direction. While backpedaling the brake cone screws reverse and spreads the brake band which presses tangentially against the hub shell and brakes the bike. Coaster brakes also can be realized with the 'spreader roller' design operating similar to a rollerramp clutch already described. While backpedaling the rollers get pressed radially outwards spreading the brake band. In both designs the brake band is attached in the brake arm, unable to revolve, because it has to transfer torque via the brake arm to the bike frame.

Braking elements

Braking

Spreader rollers

Hub shell

The hub shell as the output member transfers the torque via the hub flanges to the back wheel. It is always ball bearing mounted on both sides and supplied with bearing seats, at the driver on the sprocket side and at the brake arm or the bearing respectively on the brake side. The shell of the Spectro P5 contains 2 internal toothings for both pawls of the ring gear and the planet carrier. The shell is stepped at the brake side since the internal gearing is smaller in size there. Most of the hubs of Sturmey-Archer are not stepped, but simply cylindric. Some historic hubs have built-in pawls instead of an internal toothing. In this case the toothing is performed in the planet carrier, e.g. in the Sturmey-Archer Model 'K'.In some historic Sturmey-Archer hubs with 2 gear trains the ring gear is attached within the hub shell.

Hub shell

Internal pawls

Toothing

Gear configuration

Introduction

The past 2 submenus revealed the basic function of geared hubs and it showed several variations of the technical implementation of different speeds. The gear structure shows the layout of a specific hub, i.e. how many gear trains it contains, how these gear trains are joined together, etc. Thus there are some important parameters, which will be described here briefly: Number of planetary gear trains: In the simplest case a geared hub only contains one simple gear train achieving 2 or 3 speeds. By a triple stepped planetary gear train 7 speeds can be realized.

More complex hubs contain several gear trains thus achieving even more speeds - but different grading as well. Type of gear trains: As already mentioned simple gear trains and stepped gear trains are employed, as well as combinations of both. In the Shimano Nexus Inter 4 for example 4 speeds are realized by a stepped planetary gear train. The Sturmey-Archer model FM achieves the same number of speeds by using 2 simple gear trains joined together differential.

Direction of power transfer: A gear train can be operated unidirectional, i.e. only one direction of translation is applied, e.g. speed reducing OR speed increasing only. This is applied in Fichtel & Sachs Automatic or Duomatic hubs for example. A gear train can also be operated bidirectional, i.e. both directions of translation are applied, e.g. speed reducing AND speed increasing. This is mostly to be found in common 3 speed hubs. The well-known model H311 from Fichtel & Sachs achieves 3 speeds by using a simple gear trains operated bidirectional. Model 29 achieves the same number of speeds by using a stepped planetary gear train being operated unidirectional with speed reducing ratio only.

Simple gear train Two stepped gear trains Differential gear train

Coupling of planetary gear trains: In hubs with several gear trains the individual gear trains are often piled behind one another, i.e. switched in series. The Shimano Nexus Inter 7 for example contains 2 stepped gear trains. The first one provides 2 speed reducing ratios (output 1: Planet carrier 1) and the second one provides 2 speed increasing ratios (Output 2: Ring gear 2 and input 2: Planet carrier 2). In both gear trains the planet carriers are joined together thus achieving a total ratio by multiplying the single ratios. In other cases there are some hubs containing gear trains which are differential coupled: A very close ratio for example is realized by connecting the sun gear 1 of gear train 1 with the planet carrier 2 of planet train 2 in the 3 speed model Sturmey Archer AC. As already mentioned in Planetary gears this kind of coupling leads to many diverse possibilities of gear grading.

Ring gear Planet carrier Planetary gear train

One simple planetary gear train

Mister Johnson from the USA received a patent for a 2 speed with one planetary gear train hub already in 1895. 1902 the first 3 speed hub was produced carrying the name 'The three speed gear syndicate company', which later on became Sturmey-Archer. So hubs with one simple planetary gear train where the first historic internally geared hubs and they are still produced in their millions. One simple planetary gear train - unidirectional The simplest geared hubs only contain on simple planetary gear train which is only operated in one direction: This only provides one direct gear and a speed reducing or a speed increasing ratio. Two speed hubs where the first geared hubs of the world, in 1898 already the first 2 speed hub was produced in England named 'The Hub'. A few years later a hub from 'Wanderer appeared which can probably be found only in the museum. The 'Doppeltorpedo' from Fichtel & Sachs can be definitely found from time to time und is one of the most aesthetic geared hubs. The sprocket is situated directly on the ring gear and by the plant carrier as - the only - output this hub has a speed reducing ratio only. The sun gear can also be pushed into the internal toothing of the planet carrier for achieving a direct gear. In the 1960's

Fichtel & Sachs put the legendary Duomatic and Automatic hubs on the market, which only have speed increasing ratios. The sprocket is situated on the planet carrier here, which provides two outputs combined with the ring gear. For the direct gear the pawls of the ring gear are disengaged when pressing them radially inwards out of the toothing of the hub shell and the planet carrier conducts the force flow 1:1 to the shell. For achieving the fast gear the pawls of the ring gear get activated by a control ring and 'overrun' the pawls of the planet carrier, 'klacking' while rotating unloaded.

Duomatic planet carrier | Ring gear | Control ring

The Sachs Orbit (combinated hub) be mentioned here as well, achieving between 10 and 14 gears with a gear rim of 5 to 7 sprockets by the built-in 2 speed gear. In this case, the gear rim is situated on the ring gear which has an additional internal toothing for a sliding clutch. This clutch contains two internal pawls (for the planet carrier) and two external pawls (for the ring gear AND the shell). For the hill gear the sliding clutch is pushed out of the toothing of the ring gear and thus the hub shell is driven by the planet carriers engaging with the internal pawls of the clutch. When the clutch gets pulled into the toothing of the ring gear the hub shell is driven directly by the external pawls of the clutch. The pawls of the planet carrier rotate slower and will be 'overrun'. These boys from Sachs were pretty clever, weren't they? But we've seen through.

Orbit planetary gear train | Gear unit | Clutch

One simple planetary gear train - bidirectional

Countless 3 speed hubs all over the world are based upon the principle of a simple planetary gear train being operated in both directions. Its functionality was already presented in the previous chapters. The first 3 speed hub of the world was already produced in 1902 - from 'The Three Speed Gear Syndicate Company LTD' at that time. All 3 speed hubs with simple gear train share a driver, i.e. the sprocket is not situated upon a gear component but on a driver transmitting the power flow to the gear train via an external clutch. In all 3 speed hubs the ring gear is the input for achieving the hill gear causing the planet carrier to rotate slower as output member. The hub manufacturers applied different principles for deactivating the pawls of the ring gear in that case: Sturmey-Archer pretty often pressed the pawls radially inwards - deactivating them - by means of the radiating clutch. Fichtel & Sachs, however, often pulled the ring out of the internal toothing of the hub shell.

  

Sturmey-Acher model K Pawls activated Pawls deactivated

One stepped planetary gear train

1912 a 4 speed hub was already produced by Fichtel & Sachs containing a stepped planetary gear train and a simple gear train. Unfortunately it was not very successful. Nowadays almost every hub providing more than 3 speeds comprises at least one stepped planetary gear train. The following chapters will explain the varied range of opportunities of these gear unit types.

One non-shiftable stepped gear train - unidirectional

A stepped planetary gear trains allows achieving bigger or smaller gear ratios in a small space as we already know. In the Sturmey-Archer Fixed gear hub Model TC thus a very close ratio and a direct gear is achieved. For the hill gear the ring gear - having no built-in pawls - is driven by the radiating clutch of the driver and the hub shell is driven by the slower rotating planet carrier. For achieving a direct gear the radiating clutch engages with the cams of the planet carrier. The ring gear also rotates, but disengaged due to the missing pawls.

  

Sturmey Acher model TC Stepped planetary train Clutch

One non-shiftable stepped gear train - bidirectional

This gear version works like the standard 3 speed geared hub besides having a stepped gear train. In the Sturmey-Archer model AM in this way a closer gear ratio is achieved in contrast to the well-known model AW. The ring gear meshes with the small planet wheel- like in the TC hub as well. In some hub series Sturmey-Archer offered a version with wide ratio (simple gear train) and a version with close ration (stepped planetary gear train).

One shiftable stepped planetary gear train - unidirectional

Prior to the second world war Fichtel & Sachs offered a 3 speed hub with speed reducing ratio only - following the famous Doppeltorpedo. This interesting hub - meanwhile becoming quite rare - had two sun gears which could be slid alternately into two toothings of the axle. The ring gear was driven thus always leading to speed reducing gear ratios at the planet carrier. Additionally the small sun could be inserted into an internal toothing of the planet carrier for achieving a direct gear. The Shimano Nexus Inter 4 with rotary gear selector is another hub - with speed increasing ratio, however. Driving the large triple stepped planet carrier achieves 3 speed increasing gear ratios at the ring gear as output. The direct gear is obtained when all of the three suns are switched freely rotatable - the gear train is deactivated and the ring gear cannot transfer any torque. The power flow is now transferred 1:1 from the planet carrier to the hub shell.

Sturmey-Archer AM

Driver at planetary carrier

Stepped gear train

Sachs model 29

Suns and clutches

Shimano Nexus Inter 4

One shiftable stepped planetary gear train - bidirectional

Lots of 5 and 7 speed hubs contain this transmission type, driving the ring gear or the planet carrier by using a driver. SturmeyArcher already launched a 5 speed hub 1966 using this design. The advantage of a bidirectional stepped gear trains is its simple structure. A disadvantage, however, is the dependency of the ratios of hill gears to the fast gears, since the same internal gear is driven forward and backward. Shimano designed a 7 speed hub with two stepped planetary gear trains connected in series in order to achieve a better grading of the single speeds.

Sturmey Archer S5

Small sun fixed

Suns and clutches

Gear configuration

Multiple planetary gear trains

Combining several gear trains leads to almost innumerable possibilities - mostly they are connected in series. With its 'Tricoaster hub' Sturmey-Archer 1905 launched a hub containing two independent simple gear trains and other similar hub would follow. The highest of all feelings seems to be the speedhub from Rohloff with its three stepped planetary gear trains connected in series. Multiple single gear trains connected in series When several gear trains are connected in series the total ratio will be the multiplication of the single ratios. Model 53 from Fichtel & Sachs contained two identical gear trains being connected by a common ring gear. Gear train 1 was driven by planet carrier 1 and geared up with i=1,33 at the common ring gear as output. Gear train 2 was driven by the common ring gear and geared down with i=0,75 at planet carrier 2 as output to the hub shell. Both planet carriers had internal toothings allowing the respective sun gear to be inserted for achieving a direct gear. Speed 1 was generated when coupling sun1 with planet carrier 1 (i=1) and sun 2 being fixed (i2=0,75) leading to a total ratio of i=1x0,75=0,75 (hill gear). For achieving speed 2 sun2 was also coupled with planet carrier 2 thus leading to a total ratio of i=1x1=1 (direct gear). Speed 3 was generated when fixing sun 1 leading to a total ratio of i=1,33x1=1,33 (Fast gear). This principle was also applied in some historic Sturmey-Archer hubs before 1920. The contemporary 8 speed hub X-RF (from Sturmey-Archer contained 3 simple gear trains connected in series. Every single gear train geared up with a specific gear ratio and it contained a direct gear additionally. Skillful combining of the three single ratios lead to an equal graduation of the total ratio. Due to technical problems this hub was replaced by its successor X-RF8(W), however, which will be described in the following paragraph.

Two planetary gear trains

Planet carrier 1 and 2

Sun gears

Simple and stepped gear trains connected in series

The model X-RF8(W) from Sturmey-Archer contains 2 simple planetary trains (set 1 and 3) and a double stepped planetary gear train (set 2), all of them are connected in series. Every planetary gear trains is driven at its planet carrier and has its output at the ring gear, which is connected with the ring gear of the following set. The hub shell is driven by the ring gear of the last set, in that way that innovative hub only gears up. Another feature presents the planet carrier with two pawls meshing with the associated ring gear's teeth. When fixing a sun gear of a planetary gear train the ring gear rotates faster - as you know - and 'overruns' the pawls. If the sun rotates freely (deactivated gear) the ring gear tries to stand still but it is driven by the pawls with a ratio of 1:1 (direct gear). The clutches of the suns are interesting as well: Every single sun gear has an internal toothing which can mesh with a corresponding extendible pawl which is situated within the axle. This clutch design is easier than the shift drum of the Shimano Nexus Inter 8. Once again Sturmey-Archer shows its inventiveness.

Planet carrier with pawls

Suns with internal toothing

Extendible pawls

Multiple stepped gear trains connected in series But don't be afraid - Shimano was innovativ as well: The Nexus Inter 7 contains 2 stepped planetary gear trains connected in series. This hub comprises a rotary gear selector instead of toggle chains or indexing pins and was launched already in 1992.

The first gear train gears down (i1=0,63 and i2=0,74), it's ring gear 1 is driven by a driver and planet carrier 1 as output is connected with planet carrier 2. The second gear train with planet carrier 2 as input gear up (i3=1,36 and i4=1,55). Planet carrier 2 and ring gear 2 is the output of the hub. It is interesting how the 7 speeds are realized by fixing or releasing the 4 suns and by means of a clutch within the driver:

Speed 1: Stage 1 of train 1 with i1=0,63 is activated, the suns of train 2 remain rotatable (deactivated gear). Thus the hub shell is driven by planet carrier 2 with the most speed reducing ratio i=0,63.

Speed 2: Stage 2 of train 1 with i2=0,74 is activated, train 2 remains deactivated. Thus the hub shell is driven by planet carrier 2 with the ratio i=0,74.

Speed 3: Stage 1 of train 1 gets activated again with i1=0,63, but now stage 1 of train 2 is shifted (i2=1,36). Thus the hub shell is driven by ring gear 2 with i=0,63x1,36=0,84.

Speed 4: Stage 2 of train 1 gets activated with i1=0,74 and stage 1 of train 2 remains shifted (i2=1,36). Thus the hub shell is driven with i=0,74x1,36=0,99.

Speed 5: Stage 2 of train 1 remains activated with i1=0,74 and Stage 2 of train 2 with i4=1,55 is now shifted leading to a ratio of i=0,74x1,55=1,15 at the hub shell.

Speed 6: The driver now gets engaged with planet carrier 1, i.e. gear train 1 is a direct gear with i=1. In gear train 2 now stage 1 is activated with i4=1,36. Thus the hub shell rotates with i=1x1,36=1,36.

Speed 7: Gear train 1 remains in the direct gear and stage 2 of train 2 is activated with i4=1,55 thus leading to a total ratio of i=1x1,55=1,55. Isn't it interesting to find out the Nexus Inter 7 has no direct gear as all of the other hubs?

The Nexus Inter 8 works similar but it has the following differences: Planetary gear train 2 is triple stepped providing 3 gearing up stages, gear train 1 is non-shiftable thus providing only one speed reducing ratio. Furthermore, a direct gear is applied here.

Stepped gear train 1

Stepped gear train 2

Sun gear and clutch

Differential coupled planetary gear trains

Since 1936 several 3 speed and 4 speed hubs from Sturmey-Archer were produced providing remarkably close gear ratios. This was achieved by two differential coupled gear trains. Many of those hubs were very successful and technically pretty sophisticated.

Two permanently differential coupled gear trains Besides being connected in series, planetary gear trains can also be coupled differential, as already explained in Differential planetary gear trains in the menu Planetary gears. Both historic models AR and AC from Sturmey-Archer comprise two simple gear trains being permanently differential coupled: Gear train 1 is driven by the driver - as in common 3 speed hubs causing ring gear 1 and planet carrier 1 to drive the hub shell as output members. Sun gear 1, however, is not fixed but permanently coupled with planet carrier 2 of the second gear train thus rotating permanently. Gear train 2 is driven by ring gear 2 which is integrated within the hub shell. Planet carrier 2 (rotating slower) revolves around a fixed sun gear 2 and drives sun gear 1 (differential sun). The relationships are as follows:

Speed 1: Ring gear 1 is driven by the driver and planet carrier 1 drives the hub shell (with deactivated pawls of ring gear 1). The planet carrier 1 will rotate a bit faster - compared to a stationary sun - since the differential sun rotates as well (addition of velocities). The speed-down gearing will be closer/smaller compared to a standard 3 speed hub.

Speed 2: The hub shell is driven directly by ring gear 1 because its pawls are activated again now. This provides a direct gear.

Speed 3: The driver engages with planet carrier 1 and ring gear 1 drives the hub shell (fast gear). Ring gear 1 will rotate a bit slower - compared to a stationary sun - since the differential sun rotates as well (subtraction of velocities). The speed-up gearing will be closer/smaller compared to a standard 3 speed hub.

The AR hub is designed similar but ring gear 2 is not integrated in the hub shell but it is connected with planet carrier 1. Both hubs achieve considerably closer ratios (AC: 0,92/1/1,07) compared to common 3 speed hubs (about 0,73/1/1,36) by a differential coupling. Gear unit model AC Planetary gear train 2

Two non-permanently differential coupled gear trains

Fichtel & Sachs already placed a four speed hub on the market from 1912 to 1916 containing several planetary gear trains which will be one of the most expensive collector's item in the world.

Gear unit model AC | Planetary gear train 2 | Toothing within shell

Apart from that F & S merely produced 2 speed and 3 speed hubs until the 1980's. Sturmey-Archer, however, offered several 4 speed hubs from 1935 to 1970. Three models (AF, FM and FC) contained two differential coupled gear trains which were designed similar to the model AC, already described before. Speed 2 to 4 was applied with the same principle as in model AC, e.g. by also driving sun gear 1 a closer speed reducing or speed increasing ratio was obtained compared to a common 3 speed hub. For speed 1, however, sun gear 1 was released from planet carrier 2 and was fixed at the axle. This led to a bigger speed reducing ratio again compared to the other speeds. These 4 speed hubs contain a second clutch in addition to the clutch within the driver in order to uncouple the differential sun gear from the second gear train and to push it into a toothing on the axle.

Model ASC - probably the most sought-after fixed gear hub among hub collectors - works on a similar principle. It is operated unidirectional, however, with speed reducing ratio only. For speed 1 sun gear 1 was fixed, for speed 2 the differential coupling was activated and speed 3 was the direct gear.

Clutch 2 activated | Clutch 2 deactivated | Planetary gear train 2

A differential gear train and two stepped gear trains

The differential planetary gear train 1 described in the last two paragraphs includes the following features Transmission input 1: The differential sun gear which was driven with constant ratio by gear train 2.

Transmission input 2: The differential planet carrier or the differential ring gear optionally, because this gear train was operated bidirectional.

Transmission output: This has been the differential planet carrier or the differential ring gear respectively. In the Fichtel & Sachs Elan there is a differential planetary gear train (gear train 3) which is driven by two stepped planetary gear trains, however. Both stepped gear trains have a shared planet carrier 1/2 which is driven by the sprocket.

Transmission input 1 is the differential sun gear 3 which is directly combined with the ring gear 2 of the double stepped planetary gear train 2. For achieving a direct gear, ring gear 2 can be joined to the shared planet carrier 1/2 by a clutch. To sum up, there are 3 ratios at transmission input 1: A direct gear and two speed increasing ratios.

Transmission input 2 is the differential planet carrier 3 which is directly combined with the ring gear 1 of the triple stepped planetary gear train 1. For achieving an additional direct gear, ring gear 1 meshes with pawls of the driven shared planet carrier 1/2. These pawls drive the ring gear 1 directly (1:1) when all sun gears of gear train 1 are released (deactivated gear). This design is applied similar to the gear trains in the Sturmey-Archer 8 speed hub. To sum up, there are 4 ratios at transmission input 2: A direct gear and three speed increasing ratios.

Transmission output is the differential ring gear 3 which drives the hub shell directly via pawls forming a superposition of the velocities of input 1 and input 2.

The speed ratios of the ring gear as output were already described in the menu Planetary gear trains in the paragraph Gear trains as output member. As you can see in the video it is possible to provide speed reducing AND speed increasing ratios at the ring gear. The large differential gear train 3 has a stationary gear ratio of i12=1,3 (ring gear with 114 teeth and sun gear with 88 teeth: i12=114/88=1,295). The differential planet carrier 3 must at least rotate 1/i12=0,77 times as fast as the differential sun gear in order to prevent the differential ring gear from standing still or rotating backwards. Clever combinations of the single ratios made it possible to reach 4 x3=12 speeds. Die first 2 gears had a speed reducing ratio, the third gear was a direct gear and all further speeds were fast gears. Sachs was pretty innovative using slewable cam rods for fixing or releasing all sun gears of the planetary gear trains 1 and 2. Unfortunately, this 'hub monster' was not very successful - but technically very brilliant.

Three gear trains

Ring gear 1

Ring gear 2 / sun3

Gear changing 1

This submenu presents some mechanisms for gear shifting more detailed. By applying the typical 'German thoroughness' the clutches will be divided into two categories: Internal clutches are all shiftable mechanisms for coupling gear members within the same gear train: How will sun gears get fixed or released? How get sun gears coupled with the planet carrier? External clutches are all shiftable mechanisms for coupling gear members within the same gear trains with gear members outside the gear train. This will be explained in the next submenu. Both submenus will be a feast for the eyes for friends of fine mechanics, as promised before. Only some examples out of the multitude of geared hubs all over the world can be presented. Have fun!

Shifting of sun gears

This explains the mechanisms to couple sun gears with the axle. Coupling a single sun with the axle leads the axle to transfer the counter-forces which be needed to drive the bike. It is similar to using a cordless screwdriver: We have to hold the handle of the screwdriver firmly in order to apply the counter-force resulting from the screwing procedure. Driving the ring gear of a simple gear train for example (hill gear) leads the planet carrier to drive the hub shell. The torque at the planet carrier tries to turn the sun gear backwards when loaded - imagine a loaded planet carrier is like retarding it by hand. This imaginary retarding leads the gear train to a quasi - stationary gear, in which sun gear and ring gear have different directions of rotation, as you know. It would be sufficient to fix the sun gear in backward-direction when driving the ring gear, it could remain turnable in forward-direction or be fixed in both directions, of course. Driving the planet carrier of a simple gear train (fast gear) leads the ring gear to drive the hub shell. The torque at the ring gear tries to turn the sun gear forward when being loaded. It would be sufficient to fix the sun gear in forwarddirection when driving the planet carrier, it could remain turnable in backward-direction or be fixed in both directions, of course. In hubs with shift drum e.g., sun gears get only fixed in the direction in which the torque of the load is applied, they remain rotatable in the opposite direction.

Internal clutch External clutch Driver i motion9

Sliding block, axle toothing and teethed sun

Locking a specific sun rotationally or releasing it via pushing it with a sliding block into an attached toothing of the axle is a relatively simple way for coupling sun gears. Thus, the double stepped planetary gear train of the Sram Spectro P5 was shifted, which was already explained in chapter Internal clutch within the submenu Hub elements. The predecessor models Pentasport were almost built identically. Many historic hubs applied that basic principle in different variations: In the Fichtel & Sachs Internal clutch External clutch Driver i motion 9 Doppeltorpedo the sun gear's teeth could be pulled into an internally toothed conus which was screwed and countered on the axle at the sprocket side. The large spur-cut sun gear of the Fichtel & Sachs Model 29 allowed to be pulled into a spur-cut conus which was attached to the axle. The small sun, however, was internally toothed at its collar, which could have been engaged with a short axle toothing with round teeth. Model 53, also named 'Dicke Berta' applied the same principle for both of its sun gears. The Sturmey-Archer 4 sp hub FW has a sawtooth shaped spur toothing and the sun gear's teeth within the 5sp hub S5 are chamfered on both sides - probably in order to achieve a smoother coupling process. All models shared the same basic idea to couple the sun with an axle toothing.

Sachs model 29 Sturmey-Archer FW Sachs Double Torpedo

Sliding block and grooved sun gears

Sturmey-Archer and Fichtel & Sachs made several 5 speed hubs from 1966 on using an axle which was toothed for grooved sun gears for a certain period of time. These hubs mostly differed in the type of activation of the sun gears: The corresponding sliding block was moved by a second toggle chain, or with toggle chain and push rod or with two rods. From 1993 to 1999 launched the S5 Sprinter version with one toggle chain only. The sun gears are internally grooved - as in some other designs - but there is no axle toothing any more. The corresponding sun gets rotationally fixed when a sliding block is moved into its groove thus locking the rotary motion. The S5 sprinter hub contained 2 opposite long sliding blocks with cams protruding from the axle keeping a fixed distance when the toggle chain was pulled. The right sliding lock additionally moved the radiating clutch within the driver. This arrangement allowed Sturmey-Archer to shift 5 speeds with pulling the chain incrementally.

Sturmey-Archer blocks S5 sun gears S5 clutches

The right block locked the right sun gear when the chain was unstressed and the left block was still outside of the small sun (freely rotatable). The radiating clutch was meshing with the planet carrier resulting in the most speed increasing ratio, the 5th speed. After actuating the toggle chain the lift sliding block was pulled into the small sun (fixed now) and the right sliding block left the large sun (freely rotatable) leading to the 4th speed with smaller speed increasing ratio. When pulling the chain a bit further the right block caused the radiating clutch to disengage with the planet carrier. The ring gear now was driven directly by pawls inside the driver - the 3rd speed with 1:1 ratio. The pawls of the ring gear were deactivated when pulling the chain any further and the hub shell now was driven by the slower rotating planet carrier. The left sliding block was still within the small sun locking it leading to a small speed reducing ratio - the second speed. When finally pulling the toggle chain completely the left sliding block snapped in the grooves of the large sun and released the small one. In this way the highest speed reducing ratio - speed 1 - was achieved.

In the same period Fichtel & Sachs launched its successful 7 speed hub Super 7. Grooved sun gears were shifted with the same principle of grooves and sliding block. Sachs didn't use a single toggle chain, however, but applied two indexing pins for shifting sun gears and the radiating clutch independently by using a 'clickbox'. The interior pin moved the sliding block for locking the sun gears alternately and releasing the others. The exterior pin (pipe) moved the radiating clutch independently.

Sachs Super 7 sliding block

Super 7 sun gears

Finally, the S7 hub from Sturmey-Archer should also be mentioned, which had a rotary gear selector and was actuated by a cable drum. It contained a triple stepped planetary gear train similar to the Super 7. Sun gears and radiating clutch were not shifted by indexing pins independently but by means of two cam sleeves which converted the rotary motion of the cable drum into a S5 sun gears S5 clutches (Click the image above to download the video) Sachs Super 7 sliding block Super 7 sun gears lengthwise movement. The right sliding block was controlled by the interior cam sleeve and moved a left hand sliding block with cam via a spring. The left hand sliding block finally locked and released the three sun gears alternately when traveling backwards and forwards within the sun gears.

Sturmey-Archer S7 blocks

S7 cam sleeve

Shift drum and sun gears with pawls

1992 Shimano already launched a hub with very interesting innovations with its Nexus Inter 7: A rotary gear selector instead of toggle chains, indexing pins and clickbox was introduced. Sun gear clutches get activated or deactivated by a rotary motion of a shift drum at a specific angle. The gear structure was already explained in the menu Gear configuration and the chapter 'Multiple stepped gear trains connected in series'. The axle of the Nexus Inter 7 contains protrusions (locking protrusions) in some places, where the pawls of the sun gears either will collide with (sun gear blocked, clutch activated) or will climb over (sun gear released, clutch deactivated). The pawls of the sun gears are split: The lateral small, cam-like part glides over the shift drum while turning the sun gear and it gets lifted or it remains clinging to the outside diameter of the axle - depending on the angular position of the shift drum. The other, larger part of the pawls climbs over the protrusions - when being lifted by the shift drum (sun freely rotatable, deactivated clutch) or it collides with the protrusions (sun gear blocked).

Axle protrusions Nexus7

Nexus7 Shift drum.

Pawl of sun gear

The shift drum is a swiveling sleeve with control surfaces for the ca-sides of the sun gear's pawls. The control surfaces are slewably attached beside the protrusions of the axle and get 'sensed' by the cams of the sun gear's pawls. These pawls are generally freely rotatable in the opposite direction - like all pawls - it's shallow angle allows to climb over the shift drum as well as the protrusions without getting locked. The sun gear's pawls in the Nexus Inter 7 must be lockable backwards in gear train 1 and forwards in gear train 2. This was achieved by installing the same pawls - in right-left-configuration, however - in the sun gears with different orientation and by accordingly contriving the shift drum.

Shift drum assembled Pawl activated Pawl deactivated

The Nexus Inter 4 - which is the second hub from Shimano with shift drum - is built up more simply: It contains a triple stepped planetary gear train with speed increasing ratio only (driven planet carrier) and thus all pawls must be lockable forwards - in the same direction. Shimano applied simple spring rings there keeping the pawls of the sun gears under tension - in the Nexus Inter 7 many delicate and small torsion springs were installed.

Sun gears Sun pawls Shift drum

Pawl of sun gear Cam rods and sun gears with pawls.

Between 1996 and 1999 Fichtel & Sachs released a 12 speed hub which was very exceptional in many respects: It was the largest and heaviest geared hub in the world by then - weighing 3,5kg! Its function was already explained briefly in other chapter. Though the Elan was not that successful, unfortunately, it was technically pretty innovative - but also pretty complex. 5 out of its 6 sun gears were controlled by cam rods - i.e. getting fixed or released - this principle has been specially patented by Sachs. Profiles / longitudinal slots are milled at the perimeter of the hub axle in which the cam rods are mounted slewably. The pawls of the corresponding sun gears can either climb over the remaining bars were the rods are inserted (inactive clutch, released sun) or they can rest on the bars (active clutch, fixed sun).

Sachs Elan Shifting Cam rods Cam

The cam rods are shaped semi-circular in its lower area and roof-like in its upper area along their entire length. At the position of the sun gears, however, the upper area is shaped roof-like, but flat. All pawls of sun gears situated outside the area always glide over the cam shafts without touching the bars of the axle. The pawls always get lifted up there at the highest point of the roof-like profile gliding over the bar - regardless of the rotation angle of a cam shaft. Pawls of sun gears, however, touching the flat area of the cam shafts now can be shifted selectively by a swiveling movement of the cam rods. The flat area of a cam shaft turned clockwise acts like an ascending ramp causing the pawl to slide over the bar (released sun, inactive clutch). The flat area of a cam shaft turned anticlockwise acts like a decreasing ramp causing the pawl to get blocked at the bar (fixed sun, active clutch). For switching a sun gear it needs two opposing cam rods with a flat area at the profile at the position of the corresponding sun since every sun gears contains two opposing pawls.

Cam ring

Bearing plate

Driving pins

The mechanics for swiveling the cam rods is pretty complex and it's better not to disassemble it: There is a rotatable cam ring for every sun gear and a cam lever touching its internal contour. Turning the cam ring causes the cam lever so swing in and out while it pushes the pins of a bearing plate off which allows the bearing plate to turn backwards and forwards. The hook-shaped ends of the cam rods are both situated between two pins of the bearing plate. Turning the bearing plate finally causes the hook - and the cam rod - to swivel back and forth.

Control sleeve and extendible control pawls

Since 2004 Shimano offers an interesting 8 speed hub which has many features in common with the Nexus Inter 7. It also contains two stepped planetary gear trains connected in series with a common planet carrier. The first gear train, however, in not shiftable, it only provides a speed reducing ratio and a direct gear (2 speeds). The second (triple) stepped gear train provides 3 speed increasing ratios and a direct gear (4 speeds). In this way 3x4=8 speeds are realized in the Nexus Inter 8. All sun gears of the second stepped planetary gear train are internally toothed appropriate to 3 extendible pawls on the axle - there are no pawls inside the sun gears. The pawls are loaded with spring force and can be specifically extended (meshing with the internal toothing, clutch activated) by a slewable control sleeve or be retracted (sun released, clutch inactive). The sleeve has control surfaces - similar to the Nexus Inter 7 - which can be 'sensed' by the cams of the pawls - as to be seen on the video. Cut-outs within the control surfaces cause the cams to be released and the corresponding pawl to extend when being turned. There is only one single pawl applied for one sun gear - which is remarkable. For the biggest speed reducing gear ratio the second gear train is inactivated (deactivated gear) when all pawls are retracted - similar to the Inter 7. Thus speed 1 is achieved with a speed reducing ratio of gear train one. Not bad - Shimano's guys get more and more likable to me.

Gear unit Nexus 8

Sun toothing

Control sleeve

Cam rings and slewable control pawls

Since 2008 a revised 8 speed hub from Sturmey-Archer is available as well, the structure was already described in other chapter. Its construction was made - believe it or not - pleasantly simple: Three retractable pawls with long shanks mounted within the axle can be actuated by three cam rings. The end of each shaft is angular provided with a spring loaded cam which is located within a ring with small internal cut-outs. This internal contour of the cam rings is designed in such way that the cam of the pawl snaps into the cut-outs when reaching the designated rotational angle (deflected pawl, fixed sun, active clutch) or it gets pressed inwards (retracted pawl, sun released, inactive clutch). A cable drum revolves the three cam rings synchronously and retracts or extends all control pawls. The sun gears are internally toothed similar to the Nexus Inter 8 with an adequate profile. There is only one extendible pawl for one sun gear as well.

Control pawls

Cam rings

Activation

Coupling sun gears with the planet carrier

Some historic geared hubs allowed coupling a sun gear with the planet carrier. In this way all three gear members shared the same rotational speed, a direct gear was realized. The Fichtel & Sachs Doppeltorpedo allowed to either fix the sun (hill gear) or to connect it with the planet c arrier (direct gear). The sun gear gets pushed into the planet carrier's internal toothing using its standard gear toothing. The model 29 and the model 53, however, both contained a sun gear with additional internal toothing for being fixed at the axle. Some historic Sturmey-Archer hubs applied the same principle to push a sun gear into a planet carrier's internal toothing, e.g. model T or Model TF, as well as model FN, model A, model N und model V. This coupling principle is very easy, however, it leads to considerable wear because the toothings hit each other during the coupling procedure. There exist other solutions to achieve a 1:1 gear ratio, of course, e.g. by using a deactivated gear as it is applied in the Nexus Inter 4 or other hubs, i.e. all sun gears are deactivated. This was explained in the previous chapters.

Sun within toothing of planet carrier

Direct gear

Coupling sun gears with the ring gear

The 'miraculous hub' Rohloff Speedhub 500/14 contains several clutches to couple sun gears with ring gears. More information about it will be provided at a later date.

Coupling the planet carrier with the ring gear

The several times quoted Fichtel & Sachs Elan contains a clutch to couple the shared planet carrier 1/2 with the ring gear 2 (which is directly joined to the differential sun gear 3). To do this, three pawls pivoted in bolts with chamfered side surfaces are installed within the planet carrier meshing with a toothing of ring gear 2. The shifting unit controlling the cam rods also enables a shifting ring to move to and fro. When the shifting ring is retracted (activated clutch), the pawls mesh with the toothing of ring gear 2 and thus they achieve an interfacing to the planet carrier. When the shifting ring is extended it pushes the pawls inwards via their side surfaces disengaging the toothing. This causes the planet carrier and the ring gear to get disconnected.

Shifting ring extended | Toothing ring gear 2 | Chamfered pawl

Gear changing Introduction – External clutches

The last submenu revealed how gear members within the same gear train can be connected with each other. The question how gear members of a gear train can be coupled with gear members outside of that gear train will be answered. Often it is about sliding couplings and the specific activating and deactivating of pawls. External clutches can be divided roughly into three basic groups:

1. A driver - if existing - as the input member of a gear transfers the power flow from the sprocket to different gear members. There are of course some hubs without a driver - as already mentioned before.

2. Some hubs with several gear trains allow to couple gear members from a gear train with gear members of another gear train. This is applied in some historic Sturmey-Archer hubs with a differential planetary gear train for example as well as in the Rohloff Speedhub.

3. Finally ring gear and planet carrier as output members transfer the power flow to the hub shell as output members via several clutches thus driving the bike.

Radiating clutch TCW | Sram imotion 9 | Shimano Nexus 3

Coupling the driver with planet carrier / ring gear

Many geared hubs contain a driver holding the sprocket and transferring the power flow to different gear members - mostly to the ring gear or the planet carrier. Many drivers comprise a sliding clutch, others use a cam disk for controlling the pawls elegantly. In the first historic 3 speed hubs the entire planetary gear train was moved. In the following chapters different versions of clutches within the driver will be described. The first historic hubs with driver did not contain any sliding clutches. Sturmey-Archer did not connect the driver with the gear train by a clutch but they applied the reverse principle: In 1902 (Three speed gear) and 1905 (Model X) they launched two 3 speed hubs which allowed the entire gear train to be moved back and forth by a toggle chain. Both hubs were similar in structure comprising a long sun gear to ensure that the planets of the planet carrier always kept meshing with the sun when being moved back and forth. As usual, both hubs provided a transmission output at the planet carrier to the hub shell and at the ring gear to the shell - via pawls (Model X) or toothings. Moving the gear train allowed to couple the planet carrier with the shell (hill gear, shifting to the brake side) or to couple the ring gear with the shell (Fast gear, shifting to the sprocket side). The gear train allowed to be pushed into a toothed driver while being shifted causing either the planet carrier or the ring gear to be coupled with the driver from the inside. Additionally, the output from the ring gear to the shell could have been deactivated - for achieving the hill gear - by disengaging two toothings in the 1902 model and by pushing pawls inwards in the 1905 model.

Shimano 333 (Trimatic)

Gear unit

Axle

Drivers without sliding coupling

Unfortunately, these hubs will only be found in a museum, but in 1957 Shimano put the model 333 (Trimatic) on the market acoording to a patent of Mr. Keizo Shimano himself. The Trimatic has a lot in common with these early Sturmey-Archer hubs, since it contains a gear train as well, which allows to be moved as a whole - and a driver without sliding coupling. Planet carrier and ring gear both have internal toothings situated directly next to each other. The ring gear's toothing is discontinuous and smooth at the edge to the plant carrier's toothing. The driver contains two pairs of pawls (for planet carrier and ring gear) are arranged in such a way that a pair of pawls either meshes with a certain internal toothing when the gear train is moved (activated clutch) or it touches the discontinuous area of the ring gear and gets pressed inwards (deactivated clutch). The gears are changed as follows.

Planetary gear train

Internal toothings

Driver

Hill gear: The gear train is shifted completely to the brake side and the driver's pawls for the planet carrier touch the discontinuous area of the ring gear (deactivated). Due to the left position of the gear train the planet carrier's external pawls are meshing with the toothing of the brake side (activated) and the external pawls of the ring gear are pulled out of the toothing of the driver side (deactivated). Thus the power flow is transferred from the driver to the ring gear and from the planet carrier to the shell.

Direct gear: The gear train is shifted in the intermediate position and the driver's pawls for the planet carrier and the ring gear now touch its corresponding internal toothings (both activated). Due to the intermediate position of the gear train the planet carrier's external pawls are still meshing with the toothing of the brake side (activated), but the ring gear's external pawls are still pulled out of the toothing of the driver side (deactivated). Thus the power flow is transferred from the driver to the planet carrier and from the carrier to the shell.

Fast gear: : The gear train is shifted completely to the sprocket side, the driver's pawls for the planet carrier are meshing with its corresponding internal toothing (activated), but the driver's pawls for the ring gear now touch the discontinuous area (deactivated). Due to the right position of the gear train now the planet carrier's external pawls are pulled out of the toothing of the brake side (deactivated), but the ring gear's external pawls are now meshing with the toothing of the driver side (activated). Thus the power flow is transferred from the driver to the planet carrier and from the ring gear to the shell.

Planet carrier Ring gear Sliding block

Ring gear Drivers with sliding coupling (radiating clutch)

Since 1918 the 'K' hub from the house of Sturmey-Archer contained a driver with a sliding coupling (radiating clutch) with could be moved by a sliding block. The claw-like driver was slotted in a characteristic way allowing the radiating clutch also to be rotated with the sprocket while being moved. The lugs of the radiating clutch had three functions:

1. They allowed to mesh with a cam-like toothing of the planet carrier when the toggle chain was not pulled. Thus the faster rotating ring gear was the driving gear member and the fast gear was achieved.

2. When pulling the toggle chain one times they meshed with a wedge-like toothing of the ring gear. This led to a direct gear with the ring gear as driving member.

3. Pulling the toggle chain a second time finally led to a deactivation of the pawls of the ring gear while the clutched remained coupled. This caused the planet carrier to be the driving member and a hill gear was achieved.

Driver Model K Radiating clutch Coupling procedure

Sturmey-Archer applied this principle of a radiating clutch within a claw-like driver until 1987 with marginal modifications only. In 1970 they launched the S3C containing a driver without slots and with built-in pawls (in backward direction). From 1987 all Sturmey-Archer drivers were unslotted and with built-in pawls. Prior to this, drivers and the corresponding radiating clutches were Sliding block Driver model K Radiating clutch Coupling procedure manufactured in several versions: The driver of the K hub e.g. had 6 slots and frontal cams at its planet carrier for the clutch to mesh with. The notably successful model AW (since 1936), however, used a clutch with 4 lugs only meshing with the protruding journals of the planet pinions instead of using cams of the planet carrier.

Coupling procedure

Ring gear

Pinion journals

With the 'Universal Dreigang' - becoming extremely rare meanwhile - during the years before the Second World War Fichtel & Sachs introduced its first hub containing a driver on the market. Its claw-like driver reminds a lot of the Sturmey-Archer design. The model 55 from Sachs still contained a slotted driver and a coupling block which could be moved similar to a radiating clutch. The ring gear, however, did not have an internal wedge-like toothing but an inner contour allowing the block to engage with. Pulling the toggle chain a step further led to a deactivation of the ring gear's pawls - similar to Sturmey-Archer.

Driver Sachs model 55

Inner contour ring gear

Coupling block

The driver was splined internally similar to the Sram P5 which was already described regarding the hub elements. Its sliding coupling could mesh with a toothing of the planet carrier and a toothing of the ring gear. The ring gear was permanently connected with a pawl carrier which transferred the power flow to the hub shell. The pawl carrier could be moved for achieving a hill gear. Its pawls then were pulled out of the internal toothing of the hub shell causing the slower rotating planet carrier to be the driving gear member. Since then all Fichtel & Sachs hubs containing a driver were built according to that principle: The sliding clutch moved within an internally splined driver and it allowed the pawls of the ring gear to be pulled out of the hub shell's internal toothing. Sturmey-Archer, however, pulled pawls out of a toothing only in very few ancient hubs, later on they always deactivated the pawls by pushing them inwards.

Clutch Sachs model 515

Toothing planet carrier

Toothing ring gear

Drivers with sliding clutch and pawls

1970 the S3C coaster brake hub came onto the market with three innovations: Firstly, its driver and clutch were splined similar to the model 515 from Fichtel & Sachs. Secondly, the driver provided two rear-facing pawls which could mesh with the ring gear's internal toothing similar to the radiating clutch. When pedaling forward the clutch was allowed to turn slightly within the driver causing to the pawls to retract inwards, when pedaling backward they were extended. Thirdly, the cams at the planet carrier for contacting the radiating clutch now contained additional inclined areas. These chamfers caused the radiating clutch to be connected normally with the planet carrier when choosing the fast gear in traveling direction, but pedaling backward led the radiating clutch to release from the cams of the planet carrier. When back pedaling further the rear-facing pawls of the driver extended, engaging with the internal toothing of the ring gear and turning the ring gear backwards - not the planet carrier. This ensured to get the brake force of a hill gear in all the other speeds: The slower rotating planet carrier provides more torque for the brake screw due to the gear ratio.

Clutch within driver Coupling procedure Cam ring Shifting ring

In 1987 the AWC hub came onto the market with three innovations as well: Firstly, the chamfers for decoupling the clutch from the planet carrier when back pedaling now were applied within the clutch itself. Secondly, the driver contained forward-facing pawls in addition to the rear-facing pawls. Thirdly, the clutched did not have the radiating lugs anymore for engaging with the internal toothing of the ring gear. When pedaling forward the forward-facing pawls of the driver extended and the rear-facing pawls retracted. Thus the ring gear was driven from the inside in all three speeds. When pedaling backward the rear-facing pawls of the driver extended and the forward-facing pawls retracted thus causing the increasing of the brake force which was already mentioned. The driver's clutch only has the task to mesh with the planet carrier and to disengage the external pawls of the ring gear when touching them with its outer diameter (for the hill gear). Sturmey-Archer's subsequent drivers were all designed in that way. The driver of the Shimano Nexus Inter 3 is designed similar.

Model S3C driver Clutch within driver Coupling procedure

Model AWC driver Drivers with shifting ring, cam ring and pawls

With the Shimano Nexus Inter 7 in 1992 several innovation were brought onto the market: Finally a hub with rotary gear shifter! Two planetary gear trains connected in series and the shift drum were two further highlights. Its function was already explained in other chapter. The Shimano also contained a complex and interesting driver. The ring gear is driven by a pair of external pawls and two additional pair of internal pawls meshes with the toothing of the common planet carrier. The internal rear-facing pawls ensure that the torque from back pedaling the sprocket will be transferred 1:1 to the coaster brake via the common planet carrier - the 'coaster brake booster'. The forward-facing pawls can be deactivated by a disengageable shifting ring pressing them outward leaving the toothing. The shifting ring engages (activating the clutch) when its both journals slide into a recess of the cam ring at a defined rotation angle. This clutch allows the driver to be coupled with the ring gear or directly with the planet carrier.

Cam ring Shifting ring Braking pawls

When pedaling backward the ring gear also revolves backward (faster) since the rear-facing pawls of the driver touch the planet carrier's toothing. Shimano came up with an interesting mechanism to prevent the ring gears toothing from colliding with the pair of external pawls: The rear-facing pawls are not held in place allowing them to be turned a bit after touching the toothing of the planet carrier.

While being turned they contact a ring which will retract the pair of external pawls during its rotation. The video shows that ring releasing the external pawls again (by a spring) and turning in the internal pawls back to its initial point. The Sram I motion 9 hub is designed similar concerning the driver, but it contains a multi-stage cam sleeve. This sleeve allows controlling a shifting ring for activating or deactivating pawls - and it additionally controls other internal and external clutches.

I motion 9 cam sleeve Shifting ring Clutch

Coupling the sun gear with the planet carrier There were some interesting historic hubs from Sturmey-Archer with differential coupled planetary gear trains, as already described in other chapter. They allowed coupling the differential sun gear 1 with planet carrier 2- for achieving closer gear ratiosor with the axle. Sturmey-Archer provided a second radiating clutch which was movable within the slots of sun gear 1 also containing an internal toothing. Both clutches were shifted by sliding blocks and block 2 was arranged in such a way that it was not yet moved at the beginning of the gear shifting (as block 1), but only at the end. For speed 2,3 and 4 the second clutch remained locked in the toothing of planet carrier 2 (by a spring) thus causing sung gear 1 to revolve permanently and achieving a closer gear ratio. The hill gear finally required to pull the toggle chain completely causing sliding block 2 to pull the second clutch out of the toothing of planet carrier 2 and to engage with the axle toothing. Now sun gear 1 was fixed with the axle (larger speed reducing gear ratio) and planet carrier 2 revolved unloaded. This coupling principle was applied in the AF, FM and FC hub (4 speed) as well as in the ASC (3 speed fixed gear).

Sturmey-Archer Model FM clutch 2 Sun gear 1 Sliding blocks

Coupling the ring gear with the hub shell

The following chapters reveal how the ring gear can be connected with the hub shell. Mostly the ring gear is the shiftable gear member whereas the planet carrier mostly is connected non-shiftable.

Shifting ring gear pawls by pulling them out of engagement

When shifting into a hill gear, the power flow is transferred from the driver to the ring gear and from the planet carrier to the hub shell following the typical '3 speed principle'. Several principles for preventing the ring gear from meshing with the hub shell directly via its pawls were already mentioned. Fichtel & Sachs above all mostly resolved that by moving the ring gear with the driver's clutch thus pulling its pawls out of the toothing of the hub shell. This principle is pretty simple and it was applied successfully e.g. in the Torpedo H3111 as well as in 5 speed and 7 speed hubs. However, it needs a small, un-toothed area within the hub shell and the ring gear's toothing needs to be a little bit longer for still meshing with the planet wheels. The typical Fichtel & Sachs pawls are relatively small and it needs only a spring ring to keep them under tension.

Fichtel & Sachs driver's clutch Ring gear - long toothing and small pawls

Shifting ring gear pawls by pushing them out of engagement

Sturmey-Archer did not deactivate the pawls of ring gears by moving them - besides from some 'ancient' hubs - but by turning them to the inside. These pawls were mounted turnable with pins and kept under tension by torsion springs. One end of a pawl (chamfered) extends into the ring gear, the other end meshes with the toothing of the hub shell (screw-in ball ring sprocket side). When moving the clutch across the inner end the pawl is turned out of the toothing of the ball ring. This interesting concept was applied in some 3 speed hubs of Shimano later on, you will also find pawls mounted turnable in pins.

Sturmey-Archer cutch (AW)

Sturmey-Archer ring gear and pawls (S5C)

In the above described hubs the pawls of the ring gear were always shifted by a driver's clutch. From 1982 to 1984 there was a 2 speed hub from Shimano, the 'Change hub', without a driver, having the sprocket directly placed on the ring gear. The ring gear was toothed and meshed with pawls installed inside the hub shell. The pawls of the planet carrier meshed with a toothing of the hub shell. The change hub contained a clutch plate for pressing the hub shell's pawls out of engagement (inactive clutch), thus leading the slower rotating planet carrier to be the output member for the hill gear. With activated clutch (pawls released) the power flow was transferred from the ring gear directly to the hub shell (direct gear).

Shimano "change hub" hub shell and pawls

Clutch plate, planet carrier and ring gear

Shifting ring gear pawls by a control ring

The legendary Duomatic and Automatic hubs from Fichtel & Sachs contained a turnable control ring allowing the ring gear's pawl to shift when pedaling back or to shift at a certain speed. The old version of the Duomatic included a pawl carrier with rear-facing and forward-facing pawls and a ring gear with a special inner contour. The rear-facing pawls were completely embedded within the ring gear's inner contour and they were permanently driven. The forward-facing pawls were only partly embedded in the inner contour with the remaining part meshing with the toothing of the hub shell. When turning the ring gear in comparison to the pawl carrier by pedaling back the forward- facing pawls were pressed inward (inactive clutch) or kept released (active clutch) depending on the inner contour. Sturmey-Archer lutch (AW) Sturmey-Archer ring gear and pawls (S5C) Shimano "change hub" hub shell and pawls Clutch plate, planet carrier and ring gear The new version of the Duomatic didn't contain a pawl carrier any more since the ring gear had built-in pawls meshing with a control ring and with the toothing of the hub shell. In this version the ring gear's pawls were turned within the control ring which forced the pawls to be pressed inward or to be released depending on its inner contour.

Duomatic pawl carrier | Duomatic ring gear | Shifting operation

In the Automatic hub a control ring was turned by flyweights. The control ring allowed to release the flyweights at a specific speed causing them to engage with the toothing of the hub shell then (fast gear). The videos will illustrate the different switching operations. Since 2011 Sram offers the Automatix 2 speed hub which resembles the design of the Automatic pretty much. Sturmey-Archer has a (new) S2 Duomatic in its program, since from 1966 to 1997 a S2 'kick back' hub was offered once.

Pawl carrier | Duomatic ring gear | Shifting operation

Shifting by indexing spring and indexing sleeve

From 1960 to 1964 the Bendix Automatic hub already existed allowing to switch between two speeds by back pedaling even before Fichtel & Sachs and Sturmey-Archer launched their Duomatic and Automatic. This pretty complex hub did not contain any pawls but drive cones and drive screws similar to the already described parts in other chapter. While pedaling back an indexing sleeve with a toothing placed on the screw of the ring gear revolved one switching position further. When pedaling forward again the toothing of the indexing spring revolved one switching position further. The drive cone was pulled toward the ring gear by the drive screw. In the first switching position the drive cone was pulled against three cams of the indexing spring - which prevented the cone to get connected with the hub shell (deactivated clutch, planet carrier as output). In the second switching position the three cams extended into the three cut-outs of the cone - which allowed the cone to be pulled against the ring gear completely and to transfer its torque to the hub shell activated clutch, ring gear as output with direct gear)

Bendix drive cone | Indexing spring | Indexing sleeve

Coupling the ring gear by a sliding clutch The Sachs Orbit hubs was already described in other chapter. It contains an externally toothed sliding clutch with internal and external pawls. Its external pawls are not shiftable, they only provide the connection to the hub shell. The ring gear gets coupled with the hub shell when moving the clutch into the corresponding internal toothing of the ring gear. In this way a direct gear is achieved. Indexing sleeve

Sachs Orbit with internal toothing for coupling

Sliding clutch moved into the ring gear's toothing

This is where the descriptions of IHG systems stop; he never got around the description of Rohloff alas.

There is more information in the original V-CC pdf-file:

NCA and Public Library, at https://v-cc.org.uk/about/library/

A chronologic table of IHG's

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
1	The Hub Two-Speed Gear (Manchester Hub)	The Manchester Hub Two-Speed Gear Co.	1898	1908	2	132
2	Wanderer	Wanderer Werke AG	1901	Unknown	2	131
3	Garrard two-speed gear	The Garrard Manufacturing Co.	1902	1907 ?	2	133
4	Three-Speed Gear	The Three Speed Gear Syndicate Company	1902	1905	3	156
5	Crabbe two-speed	Components Ltd.	1903	1914	2	127
6	Pedersen three-speed hub	The Dursley-Pedersen Cycle Co.	1903	Unknown	3	225
7	Fagan two-speed gear	The Eadie Mfg	1904	Unknown	2	130
8	Dursley-Pedersen two-speed hub	The Dursley-Pedersen Co.	1904	1908	2	150
9	Crabbe two-speed coaster	Components Ltd.	1904	1914	2	127
10	Crabbe three-speed	Cycle Tool and Engineering Co.	1904	1914	3	161
11	Standard two speed	The Standard Company	1905	1906 ?	2	143
12	Change speed hub	BSA	1905	Unknown	2	129
13	Griffin two-speed hub	Griffin and Stone Ltd.	1905 ?	Unknown	2	130
14	Eadie two-speed coaster hub	The Eadie Mfg	1905	Unknown	2	130
15	Crabbe three speed coaster	Components Ltd.	1905	1914	3	161
16	X (early model)	Sturmey-Archer	1905	1908	3	172
17	Stuart two-speed hub	The Stuart Hub company	1906	1907	2	133
18	Armstrong-Triplex three-speed hub	The Armstrong-Triplex Three-Speed Gear Syndicate Ltd.	1906	Unknown	3	170
19	Humber-Cordner three-speed gear	Anti-Friction Ball Co. Ltd.	1906	Unknown	3	179
20	Corbin two-speed Model 10	The Corbin Screw Corp.	1906	1920	2	133

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
21	Simplex two-speed	Messrs. Hall and Parkes	Before 1907	Unknown	2	133
22	Mark II two-speed gear	BSA	Before 1907	1907 ?	2	118/125
23	Stanley two-speed hub	The Star Cycle Co.	Before 1907	Unknown	2	133
24	Villiers two-speed hub	The Villiers Company	Before 1907	Unknown	2	133
25	Triumph two-speed gear and hub brake	The Triumph Cycle Co.	Before 1907	Unknown	2	132
26	New Departure two-speed coaster	Messrs. Brown Bros.	Before 1907	Unknown	2	140
27	Seabrook three-speed hub	Messrs. Seabrook Bros.	Before 1907	Unknown	3	172
28	Micrometer two-speed gear	The Micrometer Engineering Co.	Before 1907	Unknown	2	137
29	Peero	Unknown	Before 1907	Unknown	2	Unknown
30	Zweigang Torpedo (Doppeltorpedo)	Fichtel & Sachs	1907	1959	2	131
31	Optimus three-speed gear	The Cycle Tool and Engineering Co.	1907	Unknown	3	152
32	C (early version)	Sturmey-Archer	1907	1908	3	156
33	Sunbeam three-speed hub	John Marston Ltd.	1907	1913	3	178
34	All speed gear	The All-Speed Gear Syndicate Ltd.	1907	Unknown	Infinitely variable	150
35	James three-speed	The James Cycle Co.	1907 ?	Unknown	3	Unknown
36	C (Tricoaster)	Sturmey-Archer	1908	1910	3	172
37	V	Sturmey-Archer	1908	1909	3	172
38	BSA 3 speed	BSA	1908	1956	3	177
39	Micrometer three-speed (Lea&Francis 3 speed)	The Micrometer Engineering Co.	1908 ?	Unknown	3	179
40	Eadie two-speed	BSA	Before 1909	Unknown	2	130

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
41	Centaur two-speed	The Centaur Cycle Co. Ltd.	Before 1909	Unknown	2	130
42	James two-speed	The James Cycle Co.	Before 1909	Unknown	2	133
43	Triumph three-speed hub	The Triumph Cycle Co.	Before 1909	Unknown	3	172
44	Crabbe-Simplex three-speed	Components Ltd.	Before 1909	Unknown	3	161
45	Stanley three-speed	The Star Cycle Co.	Before 1909	Unknown	3	178
46	X	Sturmey-Archer	1910	1914	3	172
47	N	Sturmey-Archer	1910	1921	3	172
48	Universal Torpedo	Fichtel & Sachs	1912	1916	4	222
49	A	Sturmey-Archer	1914	1921	3	172
50	FN	Sturmey-Archer	1914	1918	3	172
51	FX	Sturmey-Archer	1914	1914	3	172
52	S	Sturmey-Archer	1914	1927	3	172
53	K	Sturmey-Archer	1921	1938	3	178
54	KC	Sturmey-Archer	1922	1935	3	178
55	Dreigang Torpedo model 29, model 25	Fichtel & Sachs	1924	1942	3	150
56	Perry-Sturmey 3 speed hub	Perry Brothers	1930	1941 ?	3	178
57	KB	Sturmey-Archer	1931	1938	3	178
58	KBC	Sturmey-Archer	1931	1938	3	178
59	KS	Sturmey-Archer	1932	1938	3	127
60	KSW	Sturmey-Archer	1933	1938	3	136

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
61	T	Sturmey-Archer	1933	1941	2	133
62	TF	Sturmey-Archer	1933	1941	2	133
63	TB	Sturmey-Archer	1933	1941	2	133
64	TBC	Sturmey-Archer	1933	1941	2	133
65	TBF	Sturmey-Archer	1933	1941	2	133
66	TBFC	Sturmey-Archer	1933	1941	2	133
67	KT	Sturmey-Archer	1934	1938	3	172
68	KTC	Sturmey-Archer	1934	1938	3	172
69	DD (2 speed conversion unit)	New Departure Manufacturing Co.	Middle of the 1930's	1949	2	Unknown
70	Universal Dreigang	Fichtel & Sachs	1935	1942	3	156
71	AR	Sturmey-Archer	1936	1941	3	115
72	TC	Sturmey-Archer	1936	1941	2	116
73	Two-speed D.P.	BSA	1936	Unknown	2	Unknown
74	AW	Sturmey-Archer	1937	1954	3	177
75	AM	Sturmey-Archer	1937	1963	3	136
76	AB	Sturmey-Archer	1938	Unknown	3	177
77	ABC (AB/C)	Sturmey-Archer	1938	Unknown	3	177
78	AT	Sturmey-Archer	1938	1941	3	177
79	ATC	Sturmey-Archer	1938	1941	3	177
80	AF	Sturmey-Archer	1939	1941	4	145

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
81	Musselman 2 speed conversion unit	The Musselman Hub Brake Co.	1939	1940	2	139
82	FM	Sturmey-Archer	1939	1963	4	169
83	Esco	Esco	1939	Unknown	3	177
84	Scintilla	Scintilla AG	1940	Early 1950's	3	177
85	Vibo 3 speed	Vibo, Yverdon	1941	Unknown	3	177
86	Hercules A Type, B type	The Hercules Cycle & Motor Co. Ltd	1943	End of 1950's	3	178
87	Twin Streak	New Departure Manufacturing Co.	Middle of the 1940's	Unknown	2	143
88	FW	Sturmey-Archer	1946	1970	4	189
89	ASC	Sturmey-Archer	1946	1963	3	133
90	AG	Sturmey-Archer	1946	1984	3	177
91	FC	Sturmey-Archer	1947	1963	4	159
92	Junior Dreigang	Junior Werke Franz Weiss OHG	1947 ?	Unknown	3	Unknown
93	Junior Dreigang "B'ffel"	Junior Werke Franz Weiss OHG	1947 ?	Unknown	3	Unknown
94	FG	Sturmey-Archer	1948	1967	4	190
95	AC	Sturmey-Archer	1949	1963	3	115
96	FB	Sturmey-Archer	1949	1952	4	190
97	FBC	Sturmey-Archer	1949	1952	4	190
98	Sears 503.21	Steyr	1950's	Unknown	3	Unknown
99	JC Higgins 50320	Steyr	1950's ?	1961	3	Unknown
100	Triplspeed conversion unit	New Departure Manufacturing Co.	1950	Unknown	3	178

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
101	Novo 2 speed	Husqvarna	1950	Unknown	2	Unknown
102	B'ffel Dreigang - newer version	Junior Werke Franz Weiss OHG	1952 ?	Unknown	3	177
103	TCW Mk I	Sturmey-Archer	1952	1960	3	177
104	Multispeed Power Brake	Bendix Aviation Corporation	1952	1961	2	Unknown
105	Torpedo Dreigang model 53	Fichtel & Sachs	1953	1956	3	177
106	SW	Sturmey-Archer	1954	1960	3	192
107	Styria 3 speed	Steyr	1954	1972	3	173
108	Brampton 140-1	Brampton Fittings	1954	Middle of 1960's	3	Unknown
109	Torpedo Dreigang model 55	Fichtel & Sachs	1955	1961	3	177
110	Novo 3 speed	Husqvarna	1955	Unknown	3	Unknown
111	333	Shimano	1957	1979 ?	3	177
112	AW (reintroduced)	Sturmey-Archer	1958	2001	3	177
113	TCW MkII	Sturmey-Archer	1959	1961	3	177
114	Automatic Red Band	Bendix Aviation Corporation	1960	1964	2	149
115	TCW MkIII	Sturmey-Archer	1961	1972	3	177
116	Torpedo Dreigang model 415	Fichtel & Sachs	1961	1984	3	186
117	Torpedo Dreigang model 515	Fichtel & Sachs	1961	1975	3	186
118	Torpedo Duomatic 101	Fichtel & Sachs	1964	1970	2	136
119	Torpedo Duomatic 102	Fichtel & Sachs	1964	1973	2	136
120	Automatic Yellow Band	Bendix Aviation Corporation	1965	1969	2	149

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
121	Automatic Blue Band	Bendix Aviation Corporation	1965	1969	2	150
122	S5	Sturmey-Archer	1966	1974	5	225
123	S2 (old version)	Sturmey-Archer	1966	1972	2	135
124	S3B	Sturmey-Archer	1967	1976	3	178
125	Centrix 301	Richard Gottschalk Gevelsberg	1968	1968	3	186
126	Gazelle 3 speed	Gazelle	1968	End of 1960's	3	Unknown
127	S3C	Sturmey-Archer	1970	1988	3	166
128	AB100	Shimano	1972	Unknown	2	135
129	Torpedo Duomatic R2110	Fichtel & Sachs	1973	1984	2	136
130	Torpedo Automatic A2110	Fichtel & Sachs	1974	Unknown	2	136
131	Torpedo Dreigang model H3111, H31xx	Fichtel & Sachs	1975	1997	3	186
132	TB-100	Shimano	1975	Unknown	3	177
133	TC-100	Shimano	1975	Unknown	3	177
134	S5/1	Sturmey-Archer	1977	1981	5	225
135	Suntour	Suntour	1977	Unknown	3	177
136	SAB3 (old version)	Sturmey-Archer	1978	1987	3	178
137	3 speed SG-3S20 cartridge type	Shimano	1978	1981	3	177
138	333F	Shimano	1979 ?	Unknown	3	177
139	333G	Shimano	1979 ?	Unknown	3	177
140	333FA	Shimano	1979 ?	Unknown	3	177

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
141	Orbit (H10xxx, H12xxx, H14xxx)	Fichtel & Sachs	1980	Unknown	2	136
142	Torpedo 2x3	Fichtel & Sachs	1980	1986	3	186
143	S5-2	Sturmey-Archer	1981	1990	5	225
144	Change hub (SG-2S10)	Shimano	1982	1984	2	138
145	3 speed SG-3S21 cartridge type	Shimano	1982	1982 ?	3	177
146	5 speed Alloy	Sturmey-Archer	1983	Unknown	5	225
147	AW/A Alloy	Sturmey-Archer	1983	Unknown	3	178
148	3 speed G-3S23 cartridge type	Shimano	1983	1983 ?	3	177
149	3S	Shimano	1984 ?	Unknown	3	177
150	3CC (SG-3C23), TC-100, TC-200	Shimano	1984	1984 ?	3	177
151	3SC	Shimano	1984 ?	Unknown	3	177
152	AW NIG Columbia	Sturmey-Archer	1984	Unknown	3	178
153	AT3 Elite	Sturmey-Archer	1984	1999	3	178
154	AT5 Elite	Sturmey-Archer	1985	1999	5	225
155	SAB3 Steelite	Sturmey-Archer	1987	Today	3	178
156	Torpedo Pentasport double sided actuation (H51xx)	Fichtel & Sachs	1987	1992	5	225
157	AWC Mk1	Sturmey-Archer	1988	1991	3	177
158	AWC Mk2	Sturmey-Archer	1991	Unknown	3	177
159	5 Star NIG	Sturmey-Archer	1991	1993	5	225
160	5 Star drum Elite	Sturmey-Archer	1991	1993	5	225

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
161	AB/C	Sturmey-Archer	1991	Unknown	3	178
162	Torpedo Pentasport onesided actuation (H52xx)	Fichtel & Sachs	1992	1998	5	225
163	Nexus Inter 7 (SG-7xxx)	Shimano	1992	Today	7	244
164	S5 Sprinter	Sturmey-Archer	1993	1999	5	226
165	AT5 Sprinter Elite	Sturmey-Archer	1993	1999	5	226
166	S5C Sprinter	Sturmey-Archer	1993	1999	5	226
167	Torpedo Super 7 (H72xx)	Fichtel & Sachs	1993	1998	7	284
168	Nakano 3 speed	Nakano Iron Works Co., Ltd.	1996	1999	3	181
169	Nexus Inter 4 (SG-4xxx)	Shimano	1996	Unknown	4	184
170	Elan (Spectro E12, MH12xxx)	Fichtel & Sachs	1996	1999	12	339
171	S7 Sprinter	Sturmey-Archer	1997	2000	7	280
172	AT7 Sprinter	Sturmey-Archer	1997	2000	7	280
173	S7C Sprinter	Sturmey-Archer	1997	2000	7	280
174	Spectro 3x7	Sram	1997	2000	3	188
175	SAB5 Steelite	Sturmey-Archer	1998	2000	5	225
176	Nexus Inter 3 (SG-3xxx)	Shimano	1998	Today	3	186
177	Spectro P5 (MH52xx)	Sram	1998	2012	5	251
178	Spectro S7 (MH72xx)	Sram	1998	2012	7	303
179	Spectro T3 (MH31xx)	Sram	1998	2006	3	186
180	AB5 Steelite	Sturmey-Archer	1999	Unknown	5	225

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
181	X-RD3 Summit	Sturmey-Archer	1999	Today	3	178
182	X-RD5 Summit	Sturmey-Archer	1999	Unknown	5	225
183	X-RD7 Summit	Sturmey-Archer	1999	2000	7	280
184	X-R7 Summit	Sturmey-Archer	1999	2000	7	280
185	X-RC7 Summit	Sturmey-Archer	1999	2000	7	280
186	S-RF5	Sturmey-Archer	1999	Unknown	5	225
187	S-RC5	Sturmey-Archer	1999	Unknown	5	225
188	S-RK5	Sturmey-Archer	1999	Unknown	5	225
189	X-RF5 Summit	Sturmey-Archer	1999	Unknown	5	225
190	X-RC5 Summit	Sturmey-Archer	1999	Unknown	5	225
191	X-RK5 Summit	Sturmey-Archer	1999	Unknown	5	225
192	Speedhub 500/14	Rohloff	1999	Today	14	525
193	Dualdrive 24 / Dualdrive 27	Sram	2000	Discontinued	3	Unknown
194	SAB3	Sturmey-Archer	2001	Today	3	177
195	AB3	Sturmey-Archer	2001	Today	3	177
196	AW NIG	Sturmey-Archer	2001	Today	3	177
197	AWC(II)	Sturmey-Archer	2001	Today	3	177
198	S-RF3	Sturmey-Archer	2001	Today	3	177
199	S-RC3	Sturmey-Archer	2001	Today	3	177
200	S-RK3	Sturmey-Archer	2001	Today	3	177

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
201	Nexave Intego IF-C530	Shimano	2003	Unknown	3	186
202	AWC (2003-2005)	Sturmey-Archer	2003	2005	3	177
203	Nexus Inter 8 (SG-8xxx)	Shimano	2004	Today	8	307
204	X-RF8	Sturmey-Archer	2004	2009	8	305
205	X-RD8	Sturmey-Archer	2004	2009	8	305
206	X-RK8	Sturmey-Archer	2004	2009	8	305
207	X-RR8	Sturmey-Archer	2004	2009	8	305
208	SX-RK3	Sturmey-Archer	2005	Today	3	177
209	SX-RB3	Sturmey-Archer	2005	Today	3	177
210	RS-RF3	Sturmey-Archer	2005	Today	3	177
211	RX-RD3	Sturmey-Archer	2005	Today	3	177
212	i-motion 3	Sram	2006	2017	3	186
213	i-motion 9	Sram	2006	2010	9	340
214	RGF391	MBI Co., Ltd.	2006	Today	3	191
215	RGF391E	MBI Co., Ltd.	2006	Today	3	191
216	RGN370	MBI Co., Ltd.	2006	Today	3	170
217	RGF391C	MBI Co., Ltd.	2006	Today	3	191
218	RG236A	MBI Co., Ltd.	2006	Today	2	133
219	RG236B	MBI Co., Ltd.	2006	Today	2	Unknown
220	RGF233	MBI Co., Ltd.	2006	Today	4	191

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
221	Alfine 8 speed	Shimano	2007	Today	8	307
222	NuVinci N170S	Fallbrook Technologies Inc.	2007	2010	Infinitely variable	350
223	NuVinci N171B	Fallbrook Technologies Inc.	2007	2010	Infinitely variable	350
224	KH-Schlumpf	Schlumpf Innovations	2008	Today	2	155
225	X-RF5(W)	Sturmey-Archer	2008	Today	5	256
226	X-RC5(W)	Sturmey-Archer	2008	Today	5	256
227	X-RD5(W)	Sturmey-Archer	2008	Today	5	256
228	XL-RD5(W)	Sturmey-Archer	2008	Today	5	256
229	X-RK5(W)	Sturmey-Archer	2008	Today	5	256
230	X-RK5(N)	Sturmey-Archer	2008	Today	5	256
231	S-RF5(W)	Sturmey-Archer	2008	Today	5	256
232	S-RF5(N)	Sturmey-Archer	2008	Today	5	256
233	S-RC5(W)	Sturmey-Archer	2008	Today	5	256
234	S-RK5(W)	Sturmey-Archer	2008	Today	5	256
235	S-RK5(N)	Sturmey-Archer	2008	Today	5	256
236	S-RF3(N)	Sturmey-Archer	2008	Today	3	177
237	S-RK3(N)	Sturmey-Archer	2008	Today	3	177
238	S5C(W)	Sturmey-Archer	2008	Today	5	256
239	S3X	Sturmey-Archer	2008	Today	3	160
240	BSR (Brompton small ratio)	Sturmey-Archer	2008	Today	3	177

No	Model name	Manufacturer	Start of period	End of period	Number of gears	Gear ratio
241	BWR (Brompton wide ratio)	Sturmey-Archer	2008	Today	3	245
242	XL-RD3	Sturmey-Archer	2009	Today	3	177
243	X-RF8(W)	Sturmey-Archer	2010	Today	8	325
244	X-RD8(W)	Sturmey-Archer	2010	Today	8	325
245	X-RK8(W)	Sturmey-Archer	2010	Today	8	325
246	S2 Duomatic	Sturmey-Archer	2010	Today	2	138
247	S2C Dumatic	Sturmey-Archer	2010	Today	2	138
248	B2C Duomatic	Sturmey-Archer	2010	Today	2	138
249	Alfine 11 speed (SG-S700)	Shimano	2010	Today	11	409
250	Automatix	Sram	2010	Discontinued	2	124
251	NuVinci N360	Fallbrook Technologies Inc.	2010	Today	Infinitely variable	360
252	NARI3 Air hub	Nakano Iron Works Co., Ltd.	2010	Today	3	177
253	CS-RF3	Sturmey-Archer	2010	Today	3	177
254	CS-RK3	Sturmey-Archer	2010	Today	3	177
255	SG-3530	Shimano	Unknown	Unknown	3	Unknown
256	G8	Sram	2012	Today	8	Unknown
257	Nexus Inter 5	Shimano	2012	Today	5	206