A Technical Examination of the Planetary Transmission of the Ford Model T

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A Technical Examination of the Planetary Transmission of the Ford Model T
Műszaki elemzés a Ford T-modell bolygóműves sebességváltójáról

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Abstract
During the 19 year long production of Ford T-Model, its transmission remained unchanged. The transmission, designed by Joseph Galamb, and his team adopting Henry Ford's ideas, was developed for slightly more than a year, in a secret office. What was this transmission like? This article brings it closer to current admirers through its history, and gives an analysis of it for those, with engineering aspect of view.

Összefoglaló
A 16 millió Ford T Modell mindegyikében, ugyanaz a Galamb József és csapata által megtervezett sebességváltó volt. A tervek 1907 és 1908 között készültek egy titkos, külön a Ford T-modell megtervezésére szánt irodában. Milyen volt ez a sebességváltó? A cikk a történeti előzményeket követően felhasználói és mérnöki szempontból is ismerteti a sebességváltó fő jellemzőit.

Kulcsszavak
Ford T modell, bolygóműves sebességváltó, Galamb József, Balough Károly, Hatásfok analízis

Keywords:
Ford Model T, Planetary Transmission, Joseph Galamb, Charles Balough, Efficiency Analysis

[Mr. Ford] said, "Your first job is going to be to design a new transmission. I'm not satisfied with the transmission that we have on there now. It is not practical the way it is designed, and we've got to get a new one." **– Joseph Galamb**

"In all, I designed eight models before the Model T." **– Henry Ford**

1. HISTORY

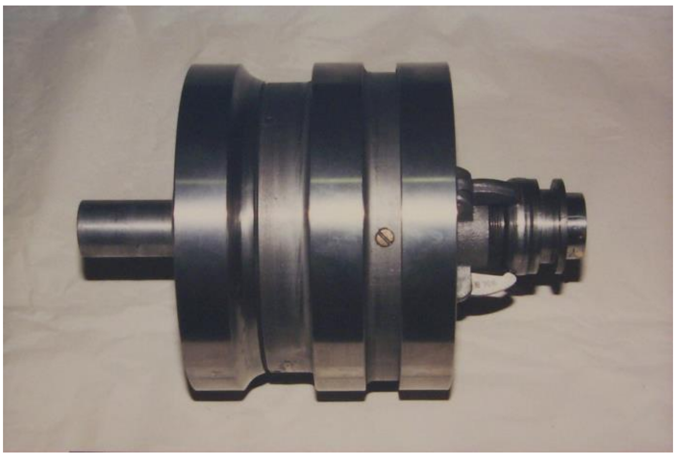
The Model T's transmission is of the planetary type and as such represents an evolutionary step from the planetary transmissions that had been used in all of the early products of the Ford Motor Company right back to the original 1903 Model A. These transmissions were not very much different in design from the planetary transmission used in a number of early American automobiles, including Cadillac, Oldsmobile and the REO. These transmissions also shared a number of faults attributable to the general design. The Model T's design team in attempting to solve these design faults took an entirely new approach to planetary transmission design that resulted in a much more reliable and long-lived planetary transmission than anything else available on the market.

The planetary system of power transmission had been used for so long in America that its original inventor is unknown. In 1906, Charles Duryea described the planetary transmission as "the first form to be largely used in America, being first regularly employed on Duryea vehicles in 1898 and afterward adopted in the Olds runabout by its many imitators, as well as in the Cadillac and Ford machines."[7]. Duryea describes the planetary type of transmission as having a spur driving gear attached to the crankshaft. Meshing into this were one to three planetary pinions, which in turn meshed into an internal gear concentric with the crankshaft. This transmission provided three speeds: one for locking the mechanism together to provide direct drive, a second gear which when the internal gear was held stationary forced the planetary gears to revolve around the spur driving gear and driving the sprocket forward at a low speed, and a third that when the frame carrying the planetary gears was held stationary would cause the sprocket to be driven in a reverse direction.

The transmissions in the Ford models before T were designed in essentially the same manner described by Duryea. They consisted of several rotating drums which enclosed the gears. The gear speed of the car and reverse were engaged by stopping one of the rotating drums by contracting a fiber-lined steel band that surrounded the drum. The lubrication of the gears and shafts was achieved by forcing heavy semi-fluid grease into the drums enclosing the gears. The transmissions were actually designed to leak their lubrication out of the drums so as to lubricate the fiber discs between the rotating drums and the braking bands surrounding each drum. On the picture 1, the rotating drums and the gears they enclosed from a 1907 Model N Ford are shown.

Picture 1.
Rotating drums and gears of Model N Ford Transmission

When all the parts are assembled together, the transmission appears as shown below. The slotted head brass screw is one of the two points by which lubrication is inserted into the transmission.



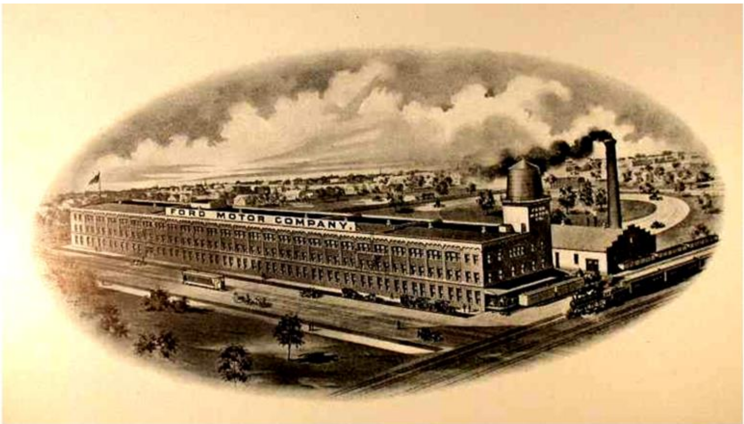
Picture 2.
Assembly of Model N Ford transmission

The complete transmission installed in a 1907 Model N showing the braking bands around the reverse, slow speed and brake drums are shown next. Note the lubricant that has leaked out from inside the drums that now coats all of the outside surfaces.

Picture 3.
Transmission installed in a 1907 Model N

The three Ford cars that immediately preceded the Model T were the N, R and S models. All three used the exact same transmission, and there were two faults common to this transmission. First, since the transmission was in the open behind the motor the dust, dirt and grime that characterized early American roads easy reached the transmission and stuck to it because of the lubricant that had leaked out from inside the rotating drums. This created a condition in which the transmission parts would wear rapidly. The second fault was the difficulty associated with replenishing the lubricant inside the drums. As indicated in the second photograph above lubrication must be forced into the transmission drums through two small slotted head brass screws in the transmission drum and the transmission output shaft. These are difficult to reach when the engine and transmission are at room temperatures, but become almost impossible to reach when the engine and transmission are hot after having just completed a run. The result was that these transmissions usually did not receive enough lubrication to prevent excessive wear on the internal parts. It appears today that more Model N, R and S cars died from a lack of transmission lubrication than from any other cause.

In January or February of 1908 Henry Ford asked Joseph Galamb and Charles Balough to set up their drawing boards and a blackboard in the northeast corner of Ford’s Piquette Avenue factory. This factory was only 3 years old and it stands on the corners of Piquette Avenue and Beaubien Street in what at the time was the northern outskirts of Detroit. Both men were trained at the Royal Technical Institute in Budapest.



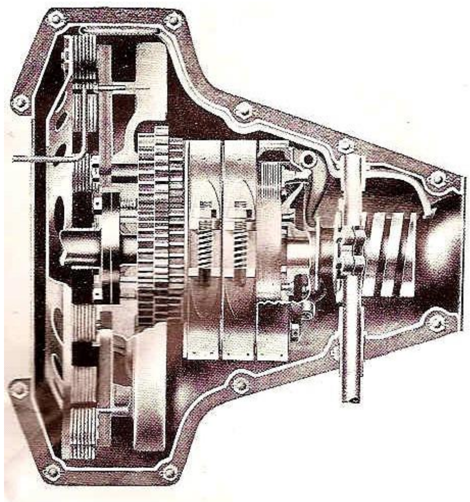
Picture 4.
Ford Motor Company Factory on Piquette and Beaubien

The experimental room where the Model T was designed was located on the 3rd floor of the northeast corner of the factory building (Picture 5).

Picture 5.
The experimental room where the Model T was designed

Charles Balough indicated in his reminiscences that while Mr. Ford was not enthusiastic about a sliding gear transmission, he wanted to experiment with it on the Model T. After completion, the car was tested on the public streets near the Ford factory. The factory area was served by streetcars which transported the workers to the factory in the morning and back home at night. The test was conducted late in the day and an accident occurred that destroyed the car. Mr. Balough thought Mr. Ford would fire him on the spot for wrecking the car, but Mr. Ford surprised him by saying "Charley, that's the best job you ever did for this company". It marked the end of the sliding gear transmission experiments and the focus on developing a better planetary transmission [5].

Joseph Galamb claims credit for most of the design work on the Model T's transmission. This design began soon after Mr. Ford had assigned him to Piquette's 3rd floor experimental room. The project took 5 or 6 months to complete. The transmission was first drawn on a blackboard. On the blackboard Mr. Ford could follow Galamb's design very closely, making any changes he did not like. Galamb determined the gear ratios and the unique design that combined the transmission and the flywheel so that the transmission rotated with and effectively became part of the flywheel. Mr. Ford wanted to keep the car as light as possible, and this design saved the weight of a separate casing or frame to hold the three planetary pinion gears.



Picture 6.
Transmission with top of casing removed. Shows Clutch, Flywheel and Magneto

When the drawing of the transmission was completed, Mr. Ford instructed Galamb to have a small brass model made. The gears and the drums were all made from brass, and the design could be tested by holding one of the drums between their fingers to make the transmission go into low, reverse or brake. “He [Mr. Ford] liked to see a model working first. He didn’t like to go just by the blueprint. He never did. He always liked to have a sample made first”. [Reminiscences of Joseph Galamb, BFRC, The Henry Ford, Acc. 65, pp. 7, 15, 16, 25].

The next innovation in the design of the transmission was coupling it directly to the engine’s crankshaft then enclosing the engine transmission in an oil tight, dust proof case. The case consisted of a cover over the top and the oil pan on the bottom. This design eliminated two of the major faults with the earlier Ford planetary transmission. First, the case kept the dust, dirt and road grime out of the transmission. Second, the transmission was constantly lubricated by the same oil as the engine. Adding oil to the engine added oil to the transmission at the same time.

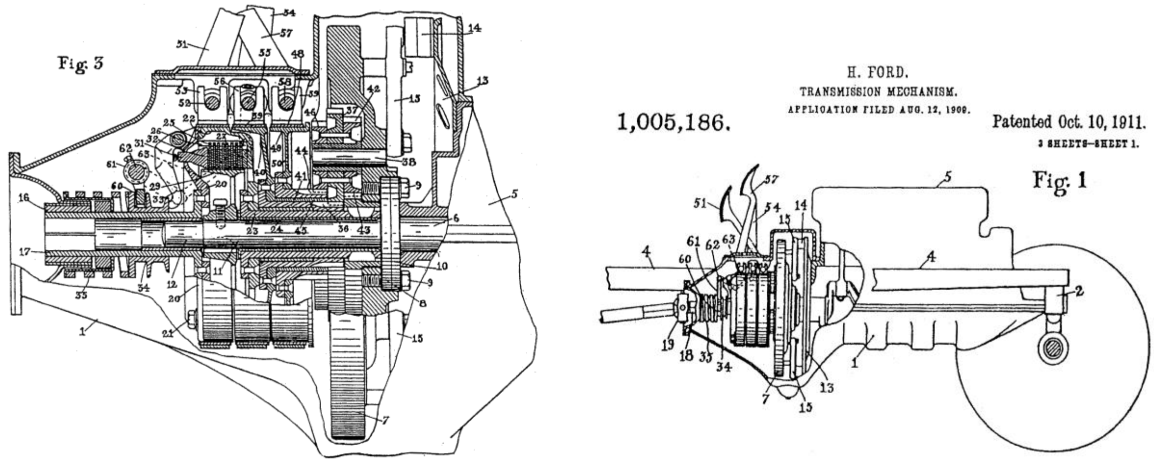


Figure 1.
Figures from US patent of the “transmission mechanism”

The final design proved to be very reliable and durable. It was used on all of the 16 million Model Ts produced worldwide from 1908 to 1927.

The T Model was announced in March 1908, slightly more than a year after the beginning of development. As a result of hard teamwork during this period of time a car with a revolutionary transmission had been made, from which afterwards 16 million pieces were sold. The transmission is perhaps the only part which went unchanged throughout the 19 years of production. The design made by Galamb led design group, was patented by Henry Ford. The claim of patenting was handed in on 10th of August 1909, and it was accepted with patent number 1,005,186 on 10th of October 1911. The simplicity, good efficiency, and load distributing of planetary transmission made it successful not just in automobile industry but in aviation too [2]. During the first World War Galamb designed a planetary transmission for tanks as well [1].

2. PRINCIPLE OF WORKING

On the fig. 2 is shown the main section and the kinematical outline of the transmission. Element **A** is the carrier of planetary gear, which is in the same time the flywheel mounted on the crank-shaft of the motor. On carrier there are three pins placed in 120 deg. On these pins are mounted the planet gears (Each planet gear consist of three, **H**, **G** and **K** gears). The planet gears are coupled with **B**, **F** and **J** sun gears, which lie in the same axis as the crank-shaft. Sun gear **B,** through friction clutch **C** is directly connected to hollow shaft **D** (the outgoing shaft which with two cone-gears connected to it, drives the wheels of the car). Sun gears **F** and **J** can be fixed by putting into use brake drums **I** and **E**.

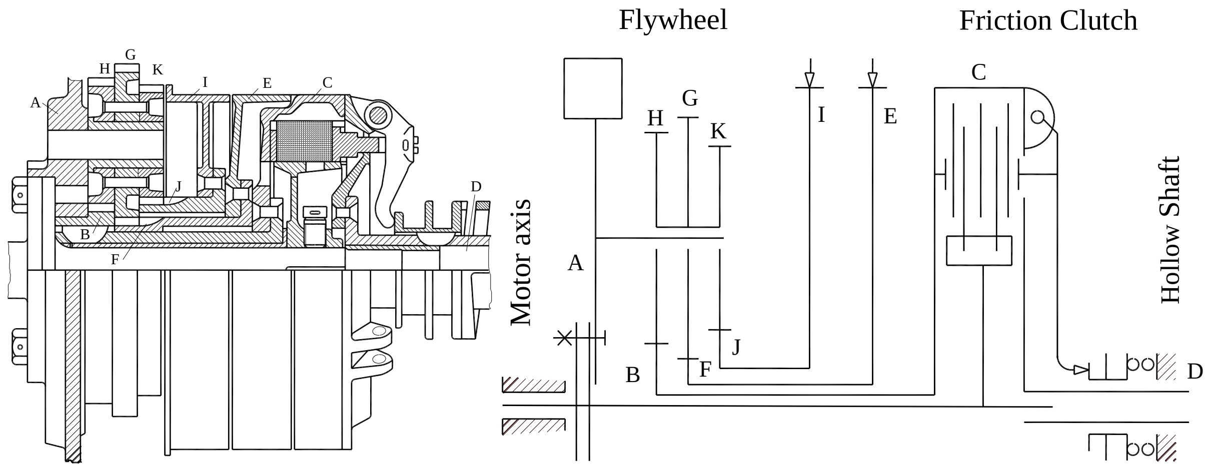


Figure 2.
The of sectional view and kinematical sketch of Ford T-model transmission

There were two forward and, a reverse speed available. To go into reverse and to low speed were needed brake drums, for high speed the friction clutch. The gears of transmission were coupled permanently, so there was no chance for teeth to become damaged at the speed change.
The teeth numbers of the planetary gear were as the following:

$z_H = 27$ $z_G = 21$ $z_K = 30$ $z_B = 27$ $z_F = 33$ $z_J = 24$

2.1 Reverse

By fixing brake drum **I** during a turn of crank-shaft, gear **K** rolls down on sun gear **J** and performs a revolution z_K/z_J. In special case when $z_K/z_J = z_H/z_B$ gear **B** would be still. Since the ratios are differ from each other (z_K/z_J = 1,25 and z_H/z_B =1) gear **B** is moved. The transmission ratio realized in this case is 1:4.

2.2 Low Speed

To get into low speed, fixing of brake drum **E** is needed. Transmission ratio realized was 1:2,76.

2.3 High Speed (direct connection)

To shift into high speed, friction clutch **C** must be utilized. In this way the crank-shaft of the motor will be directly connected with outgoing shaft **D**. The outgoing revolution is the same as the revolution of the motor. Conical wheel transmission ratio placed on the rear axle is 1: 3,64. The resulting transmission ratios, appearing on wheels of car are as follows:

Resulting transmission ratio *Sheet 1.*

LINK	RATIO
Low Speed	1:10,5
High Speed	1:3,64
Reverse	1:14,56

2.4 Handling of transmission

For starting the motor the driver should put the handbrake on. This meant in the same time the release of the friction clutch. On startup, while putting the handbrake off, the left pedal should be half way pressed. In this way the vehicle is put in idle speed. With continuing to press the pedal to the end, brake drum **E** will be fixed, and the car starts up in low speed. For high speed, the pedal has to be simply released since with this the friction clutch is switched on.

For reverse speed, first left pedal should be pressed halfway to switch the friction clutch off. Then the middle pedal must be pressed to the end, which will fix brake drum **I**. The third pedal is the brake. Thus with the transmission of Model T diverting was possible without taking hands off the steering wheel.

Sorensen wrote the following [2]: „This was a remarkable transmission. I'm sure many old-timers remember the stunts they could perform with it. It was possible to teeter the car back and forth simply by stepping first on the low and then on the reverse pedals. By releasing the low and then reversing that motion a man could do almost anything he wanted to get the car out of difficulty when in danger of bogging down in a rough country road. No transmission in today's cars could give that type of performance…".

3. EFFICIENCY ANALYSIS

In the transmission there are two O + O (outer + outer) type planetary gears of different gear ratio built in. That is, two separate basic types of such kind, which have double (**H, K** and **H, G)** planet wheels, and which planet wheels are coupled with (**B, J** and **B, F**) sun wheels (Figures 4a and 4b).

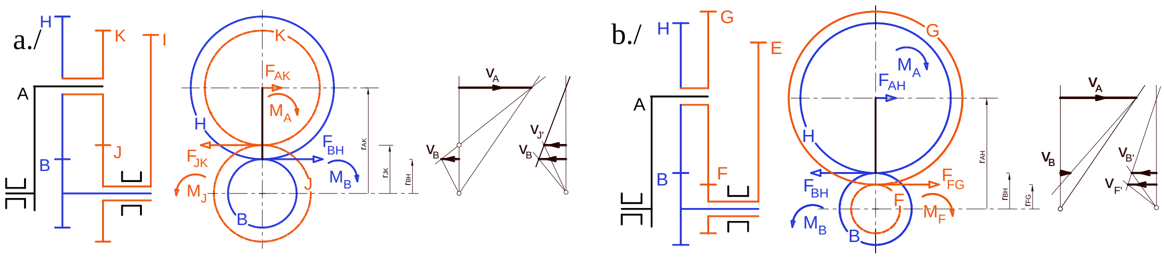


Figure 4.
Force and speed diagrams of transmission in reverse (a./) and in low speed (b/.).

Let's examine the transmission and efficiency relations first in reverse, that is when brake drum **I** is fixed. On the Figure 4 is shown force diagram calculable from external moments, the speed diagram of reverse, and of stationary carrier. The gear ratio of reverse can be obtained from the speed diagram. Let's state the peripheral speed in two different ways. First we state the peripheral speed sameness using planet gear pin center and carrier **A,** and angular speed ω_A . Second, using the pitch radius of planet gear **K** and it's angular velocity ω_K [3]:

$$A\omega_A = K\omega_K \text{, from where } \omega_A = \frac{K}{A}\omega_K . \tag{1}$$

Similarly at B-H gear coupling, the peripheral speed of coupling's pitch point:

$$-B\omega_B = -(H-K)\omega_K \text{, from where } \omega_B = -\frac{H-K}{B}\omega_K . \tag{2}$$

After witch the transmission ratio is:

$$i_{BA} = \frac{\omega_B}{\omega_A} = -\frac{H-K}{B}\cdot\frac{A}{K} = 1 - \frac{HJ}{BK} . \tag{3}$$

Using the known teeth numbers, on the base of [4] we find:

$$i_{BA} = 1 - \frac{z_K \cdot z_B}{z_J \cdot z_H} = 1 - \frac{30\cdot 27}{24\cdot 27} = -0{,}25 = 1:4$$

The η_b efficiency of planetary gear can be obtained from the above calculated transmission ratio and efficiency η_f at stationary carrier (that is, the efficiency of gear coupling). If the power flow goes from **A** to **B**, then the power balance can be written as:

$$M_A\omega_A\eta_b + M_B\omega_B = 0 . \tag{4}$$

On the other hand, if the carrier **A** is stationary, the power flows from **J to B** which has the following power balance:

$$M_J \omega'_J \eta_f + M_B \omega'_B = 0\,. \tag{5}$$

Presuming that the external moments are independent from working mode, and their resultant is zero:

$$M_A + M_B + M_J = 0\,. \tag{6}$$

From the speed diagram of stationary carrier mode (ω'_a=0) can be obtained that

$$B\omega'_B = \frac{H}{J} J\omega'_J\,,\ \text{that is}\ \ \frac{\omega'_B}{\omega'_J} = \frac{HJ}{BK} \tag{7}$$

If relation (6) is divided by M_B then

$$\frac{M_A}{M_B} + 1 + \frac{M_J}{M_B} = 0 \tag{8}$$

but MJ/MB is expressible using relations (5), (7), and (3):

$$\frac{M_B}{M_J} = -\frac{\omega'_B}{\omega'_J}\frac{1}{\eta_f} = -\frac{1-i_{BA}}{\eta_f}\,, \tag{9}$$

if we substituting it into (8) we have:

$$-\frac{M_A}{M_B} = 1 + \frac{M_J}{M_B} = 1 - \frac{1-i_{BA}}{\eta_f} \tag{10}$$

After these, the efficiency of planetary gear expressed from (4):

$$\eta_b = -\frac{M_B}{M_A}\frac{\omega_B}{\omega_A} = \frac{i_{BA}}{1-(1-i_{BA})/\eta_f}\,. \tag{11}$$

With the given data and with assumed gear coupling efficiency η_f = 0.9 we have:

$$\eta_b = \frac{-0{,}25}{1-(1+0{,}25)/0{,}9} \approx 64{,}3\%$$

In same way can be deduced that at the low speed (Fig. 4b), that is with fixed brake drum **E,** instead of relation (3) we obtain the similar

$$i_{BA} = \frac{1}{i_{AB}} = 1 - \frac{HF}{BG} \tag{12}$$

transmission ratio. Using tooth numbers instead of pitch radius [3]:

$$i_{BA} = 1 - \frac{z_G \cdot z_B}{z_F \cdot z_H} = 1 - \frac{21 \cdot 27}{33 \cdot 27} = -0{,}363 = 1:2{,}76 \tag{13}$$

The relation of efficiency for working mode shown on figure 4a :

$$\eta_b = -\frac{i_{BA}}{1-(1-i_{BA})\eta_f} = -\frac{0{,}363}{1-(1-0{,}363)\cdot 0{,}9} \approx 85\% \,.$$

4. SUMMARY

Since the efficiency at reverse and at forward speed is less than the assumed gear coupling efficiency η_f = 90% they are in unfavorable working mode zone. However, in practice, because of short duration of reverse mode, it's less disadvantageous. For going forward, efficiency of 85% which is not bad. The efficiency could be enhanced by increasing of η_f and with slight modification of tooth numbers.

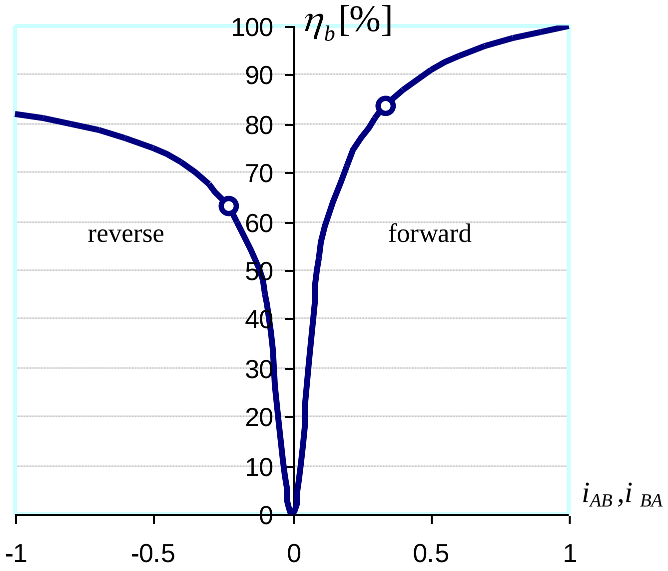


Figure 5

The efficiency of planetary gear as function of different transmission ratios

Figure 5 shows the efficiency of planetary gear as a function of various transmission ratios. The points show the values concerning Model T Ford transmission.

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