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8HP70 Automatic Transmission- Basic Design Analysis and Modular Hybrid Design Recommendations

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ABSTRACT:*Hybrid vehicles offer a huge potential for fuel consumption improvement when compared with conventional vehicle power trains. However, the sales volumes of the hybrid vehicles form a very small percentage of the total volume. In the light of uncertain future volume developments, series-parallel hybrid offers the advantage of modular design aspects, which is one of the key criteria for cost reduction and the re-use of parts. This paper analyses the modular hybrid design compatibility of 8HP70, one the most common automatic gearbox in the automotive industry. The paper first analyzes the basic design of the transmission and then provides different parallel hybrid configuration options that the transmission can be used with.*

I. INTRODUCTION

To overcome the current environmental issues and increasing fuel prices, hybrid electric vehicles (HEV) and electric vehicles (EV's) are gaining more prominence. Vehicles like Toyota Prius and GM Volt have shown impressive sales numbers in the past decade. These vehicles use power split hybrid configuration that requires special power split device and complicated control algorithms. However, it is essential that many other vehicle manufacturers, that use only conventional powertrains, should also consider providing hybrid options in their lineup. One such approach is the conceptof modular hybrid transmission designs.Using such designs, hybrid functions can be augmented in the existing powertrain with relative ease.The level of hybridization can be determined depending on the fuel economy requirements of the vehicle. For example, up to eight percent of fuelconsumption in passenger cars can be saved alone by using amicro hybrid, particularly for driving conditions in inner citytraffic. This paper explores various hybrid configuration that can be achieved using readily available components in the market. The paper first discusses the basic design of the 8HP70 transmission. Then, the various series-parallel hybrid configurations suitable for modular approach are discussed.

II. TRANSMISSION DESIGNANALYSIS

The stick diagram of 8HP708-speed transmission is shown in Fig 1. The transmission has four planetary gear sets named PGT 1, PGT 2, PGT 3 and PGT 4. To make multiple gear ratios possible, the transmission has two brakes (A and B) and three clutches (C, D, and E). The clutch diagram and the gear ratios of this transmission is given in TABLE 1.

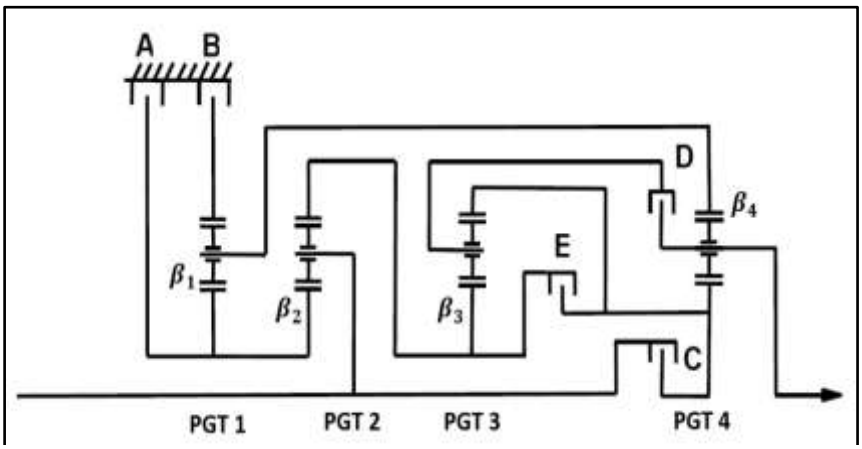

Fig 1.(Source: [2])

Table1(Source: [2])

Gear	Brake		Clutch			Ratio i	Gear step
	A	B	C	D	E		
1	●	●	●			4,696	
2	●	●			●	3,130	1,50
3		●	●		●	2,104	1,49
4		●		●	●	1,667	1,26
5		●	●	●		1,285	1,30
6			●	●	●	1,000	1,29
7	●		●	●		0,839	1,19
8	●			●	●	0,667	1,25
R	●	●		●		-3,297	Total 7,05

The characteristic equations of the four planetary gear sets are given below:

$$\boldsymbol{\omega_{S1} + \beta_1 \omega_{R1} + (1 + \beta_1)\omega_{C1} = 0}$$
$$\boldsymbol{\omega_{S2} + \beta_2 \omega_{R2} + (1 + \beta_2)\omega_{C2} = 0}$$
$$\boldsymbol{\omega_{S3} + \beta_3 \omega_{R3} + (1 + \beta_3)\omega_{C3} = 0}$$
$$\boldsymbol{\omega_{S4} + \beta_4 \omega_{R4} + (1 + \beta_4)\omega_{C4} = 0}$$

In these equations ω refers to the angular speed of the various components indicated by its subscript (S - sun, R- ring and C- career). The planetary gear parameter β is defined as the ratio between the number teeth of the ring to the number of teeth of the sun gear for the respective gear sets. Using these equations, the information from the stick diagram and the gear ratios, the $\boldsymbol{\beta_1}$, $\boldsymbol{\beta_2}$, $\boldsymbol{\beta_3}$and$\boldsymbol{\beta_4}$ values were determined:

$$\boldsymbol{\beta_1} = 2.0$$
$$\boldsymbol{\beta_2} = 2.0$$
$$\boldsymbol{\beta_3} = 1.61$$
$$\boldsymbol{\beta_4} = 3.696$$

Additionally, the torque values of all the clutches and brakes in static condition was computed as mentioned in TABLE 2. Each torque value is expressed as a magnitude of the input torque.For example, in the first gear, torque on A is 1.232 times input torque and so on.

All the values derived in TABLE 2 can be used to model the 8P70H transmission for static conditions. For, the dynamic conditions, the calculations get complicated and is beyond the scope of this paper. However, the torque values in the table give us a fair idea of the magnitude of torque that the clutches and brakes will experience. In fact, in one of the hybrid configuration, integrated starter element (ISE) is used in place of torque converter. In such cases, the torque capacity of the clutches or brakes used as a part ISE becomes critical.

Table2

	Engaged Clutches	T_A	T_B	T_C	T_D	T_E	T_{out}
1st	A, B, C	1.232	2.464	1.0	0.0	0	4.697
2nd	A, B, E	0.488	1.643	0.0	0.0	0.667	3.131
3rd	B, C, E	0.0	1.104	-0.656	0.0	1.104	2.104
4th	B, D, E	0.0	0.667	0.0	0.396	0.515	1.667
5th	B, C, D	0.0	0.287	0.573	0.743	0.0	1.282
6th	C, D, E	0.0	0.0	1.0	1.0	-0.383	1.0
7th	A, C, D	-0.161	0.0	0.518	0.839	0.0	0.839
8th	A, D, E	-0.333	0.0	0.0	0.667	0.411	0.667
Rev	A, B, D	-1.655	-2.644	0.0	1.740	0.0	-3.30

III. MOTOR/ GENERATOR AND HYBRID MODULE UNITS

This section describes the two most important components required for realizing various hybrid configuration usingthis transmission: motor/generator unit and hybrid coupling module.

3.1 Motor/generator unit:

To convert the 8-speed transmission into hybrid system, compact motor/generators are required. The motors used here will be different from conventional motors. These have permanently excited neodymium iron boron magnets so no electric current is needed to excite the field. This means that the power electronics can be smaller. Many companies have designed robust motors specifically for 8HP70. One such motor has been shown in Fig 2.

3.2 Hybrid modules:

The hybrid modules usually consist of electric motor, torsional damping, and wet clutch integrated into a single unit. This unit aims at integrating the module into existing driveline architectures without taking up additional installation space.These hybrid modules are available in the market and are already in mass production. One such hybrid module unit has been shown in Fig 3.

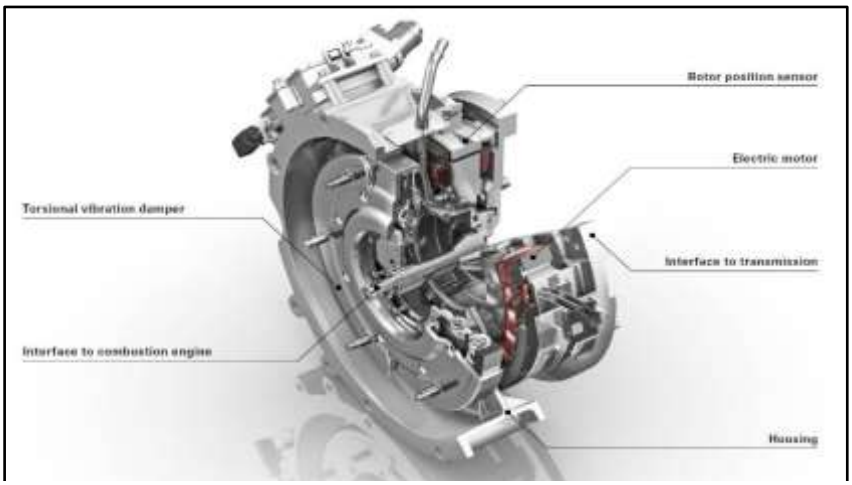

Fig: 2(Source: Into the future with e- mobility- ZF Product catalogue)

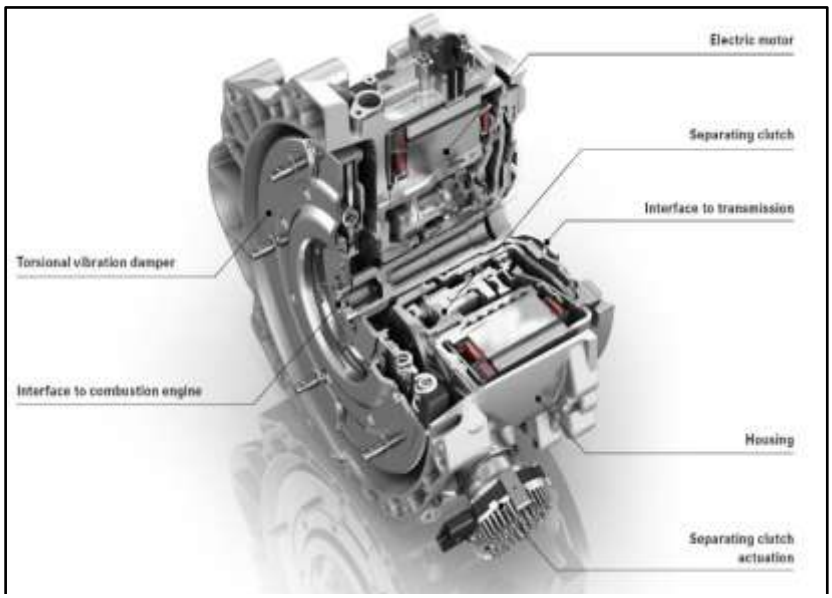

Fig: 3 (Source: Into the future with e- mobility- ZF Product catalogue)

IV. MILD AND MICRO HYBRID CONFIGURATIONS

Thefollowing two sections will describe the different hybrid configurations that can be used for the 8HP70 automatic transmission. The primary design objective is maximum compatibility with the core elements of the basic transmission without having to resort to additional measure. The secondary objective is to keep the need for extra installation space to a minimum.

In this paper, we will use SAE's numbering conventionto denote the location of the motor as follows (also shown in Fig 4):
P0/P1 - use of a BSG/ISG for start-stop functionality
P2 - an electric motor sandwiched between the ICE and transmission
P3 - an electric motor coupled to the lay-shaft of the transmission
P4 - rear axle powered by electric motor in FWD vehicle

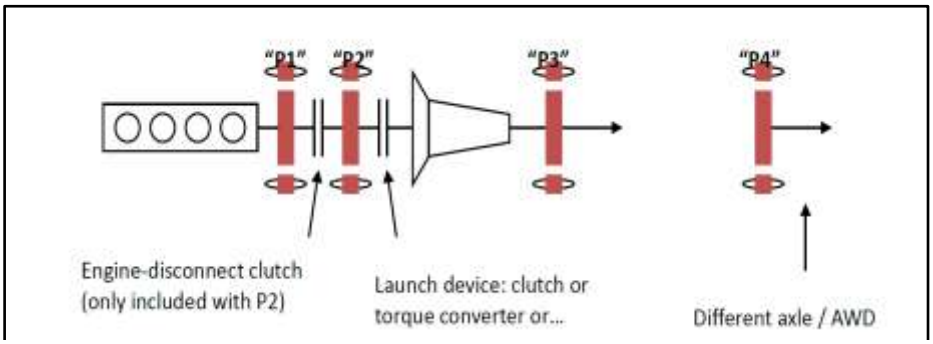

Fig: 4 (Source: [5])

4.1 P0/P1 Hybrid Configurations:
The general architecture to implement P1 hybrid options for thegearbox is shown in Fig 5.

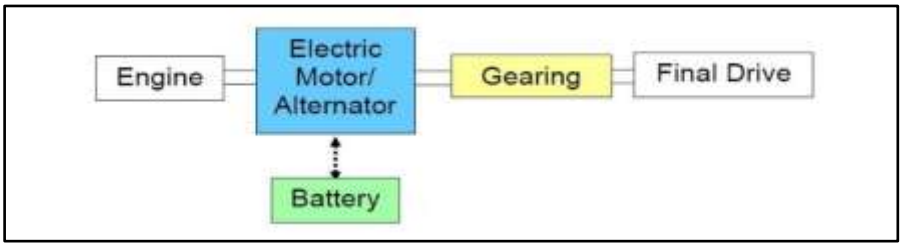

Fig: 5 (Source: [5])

4.1.1 Micro Hybrid

Micro Hybrid includes an integrated starter generator and energy recuperation system. In this variant of the transmission, there is an additional installation of an electric motor between the transmission and the combustion engine. Amotor or the starter/generator motor, mentioned in the previous section, can be used for this purpose. The electric machine is usually in a power range between 10 and 20 KW.

4.1.2 Mild hybrid

"Mild" stands for a hybrid system which does not allow electric driving. The motor only supports the engine during high power demands. For example, in the case of full throttle operation, acceleration can be reinforced by boosting (the combination of full combustion engine and electric motor torque). In this case, too, the electric machine is in a power range between 10 and 20 kW. Fig 6 shows the placement of motor for mild hybrid configuration.

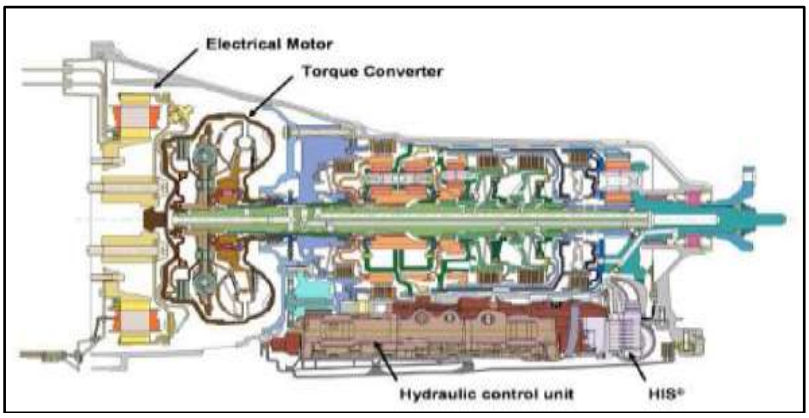

Fig: 6 (Source: [1])

4.1.3 Mild+ hybrid

"Mild+" basically includes some functions of a full hybrid system - i.e. electric driving or crawling without combustion engine. Therefore, the topology for this transmission concept requires an engine-separating clutch as shown in Fig: 7.

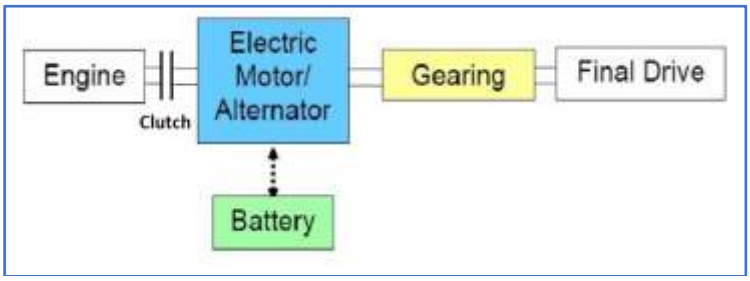

Fig:7

V. FULL HYBRID CONFIGURATIONS

The 8HP70 transmission can effectively be used in multiple series-parallelhybrid configurations with and without torque converter.Although it is possible to think of many other configurations, only some of them can be realized using minimum number of components. Most of the configurations used in this paper require only those components that were described in the previous section as the goal of the paper is to reduce system complexity.In the following block diagrams, P1, P2 and P3 are motor/generators whose specifications are selected based on the power requirements and fuel efficiency targets.

5.1 P1 - P3 configuration with Torque converter

In this configuration, the engine can charge the battery via the P1 motor/generator. Additionally, regenerative braking is also possible through P3 motor generator. In motor-only drive mode, P3 drives the wheels and the clutch C1 is fully disengaged as the engine is used only to charge the battery. In such a configuration, the IC engine can be made to operate in an optimum region of high fuel economy. In pure electric mode, the engine is switched off and the motor P3 drives the vehicle using the battery power.To drive the vehicle in full IC engine mode, the engine separating clutch C1 can be engaged.

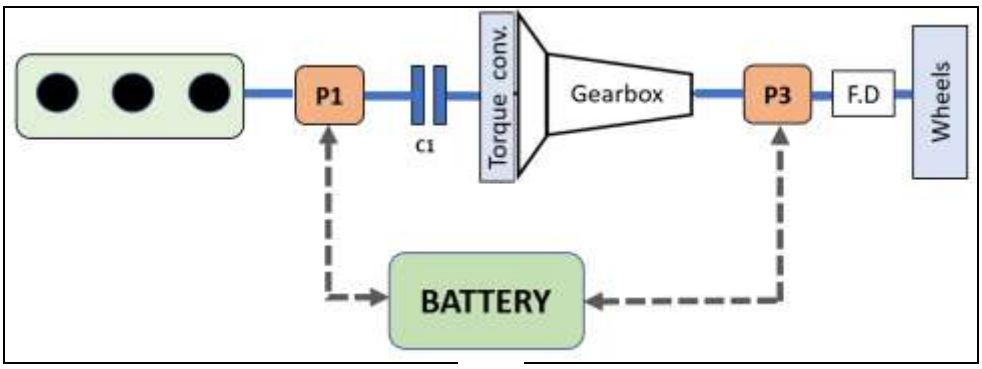

Fig: 8

5.2 P1-P2 configuration with Torque converter

This configuration is same as the previous except that the location of the motor has been changed. Placing the motor P2 before the gear box makes it possible to use less powerful motor since the torque multiplication can be done by the gearbox. However, implementing regenerative braking becomes difficult.

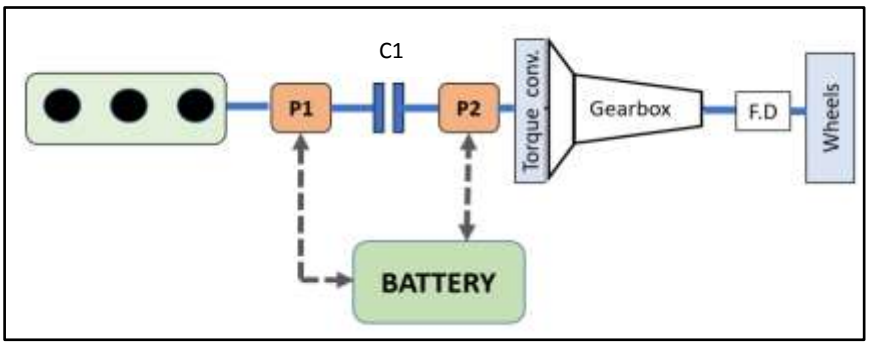

Fig: 9

5.3 P2P3 Switching configuration with Torque converter

In this configuration, the hybrid controller can switch between P1-P2 and P2-P3 configurations. Engaging clutch C1 will connect the engine to battery for charging. Engaging clutch C2 enable regenerative braking to take place through motor/generator P3.

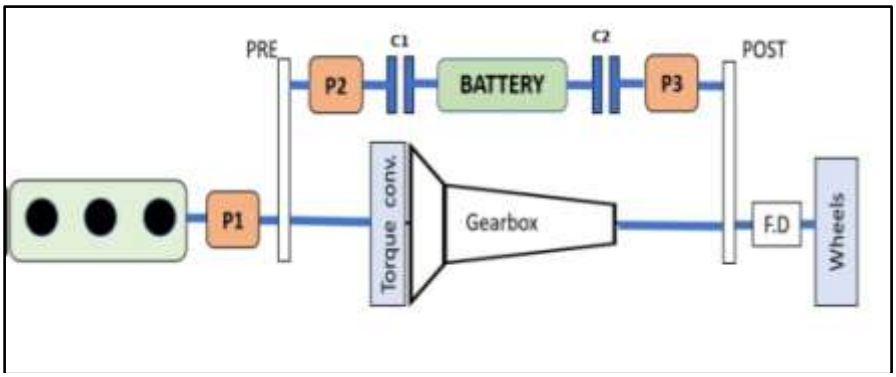

Fig: 10

5.4 Hybrid configurations using Integrated starting element

All the above configurations can be achieved with 8P70H transmission without using the torque converter. Here, in the purely electric driving mode, the electric motor is used as starting device. In a combined or purely combustion-engine powered operation, setting-off is enabled by means of an 'Integrated starting element' (IAE).In IAE, brake B, which is a wet multidisc shift element in the basic transmission, can used as a starting element. The location of this element in the gearbox is shown in Fig 12.In order to implement the IAE, some modifications to the gearbox is required. This includes extending the diameter of the multidisc package, increasing the number of multidisc, and improving the cooling. Thus, the power transfer capacity and the thermal load capacity of the starting element can be increased. Some studies have rated this IAE starting element to be suitable for starting torques of up to 550 Nm.

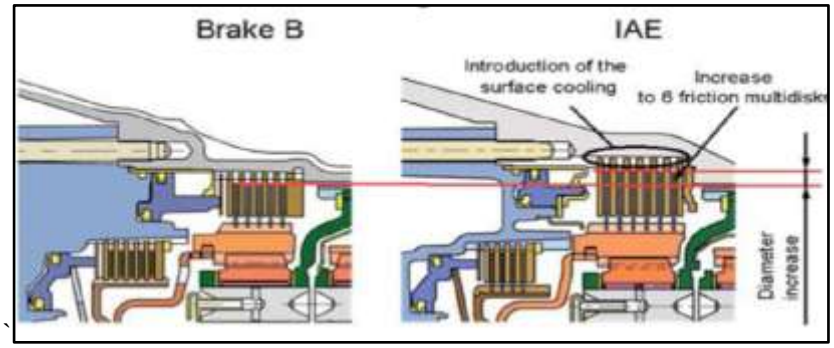

Fig: 11 (Source: [1])

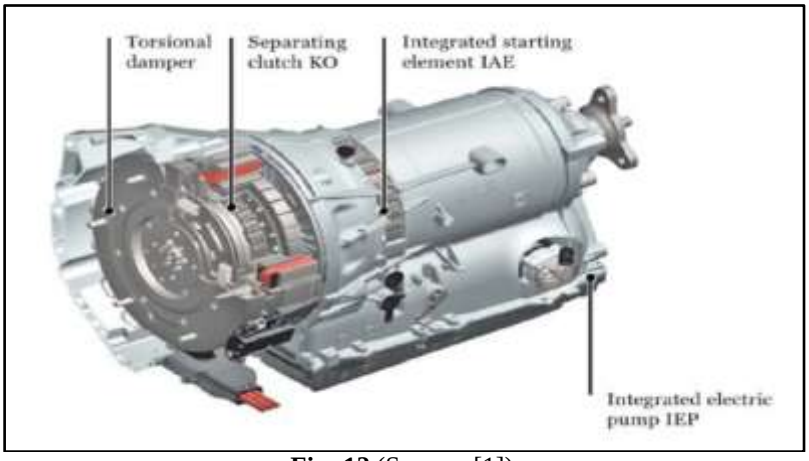

Fig: 12 (Source: [1])

VI. CONCLUSION

The design analysis of the 8P70H transmission gave us the torque values and the planetary gear parameters. These values are crucial in modelling the transmission for any application. It is evident that converting the existing transmission into a hybrid drive line can help in contributing to the reduction of CO_2 emissions in vehicles. However, because of questions related to likely market penetration and high BOM costs, hybrid drive development represents a huge economic challenge. In such a scenario, the modular kit can help reduce some of the burden. This paper has taken a conventional transmission as an example and has given recommendations for hybridization. As mentioned before, the paper has used minimum additional components, most of which have been designed to be compatible with 8P70H. Based on cost/benefit analysis, a suitable configuration can be selected and applied in a real vehicle. The same analysis can also be performed for other automatic transmissions and possible hybrid configurations can be found.

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