GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Spring Semester 2000

Design
EXAM AREA

Assigned Number **(DO NOT SIGN YOUR NAME)**

- **Please sign your name on the back of this page—**

Ph.D. Qualifier Examination
Georgia Institute of Technology
Design Written Questions, Spring 2000

PLEASE ANSWER BOTH QUESTIONS

QUESTION 1

Starter Motor Design Analysis

In Fig. 10.5, the drawing of a Lucas starter motor of an automobile engine is given. Basically, a starter motor is an electric motor that can run on the 12 Volts supplied by your car battery. Items 28 through 35 are the various components of the electric-motor part of the starter motor. If the starter motor is engaged, the motor will drive the starter pinion (item 22). The starter pinion drives the ring gear on the engine flywheel (not shown). The flywheel is connected to the engine crankshaft and the induced rotation starts the combustion cycle of the engine. Once the starter's pinion is engaged with the ring gear on the flywheel, the engine flywheel rotates. The gear ratio between the flywheel gear and the starter pinion is 11 to 1. The starter motor provides 2 kW of power to crank the engine.

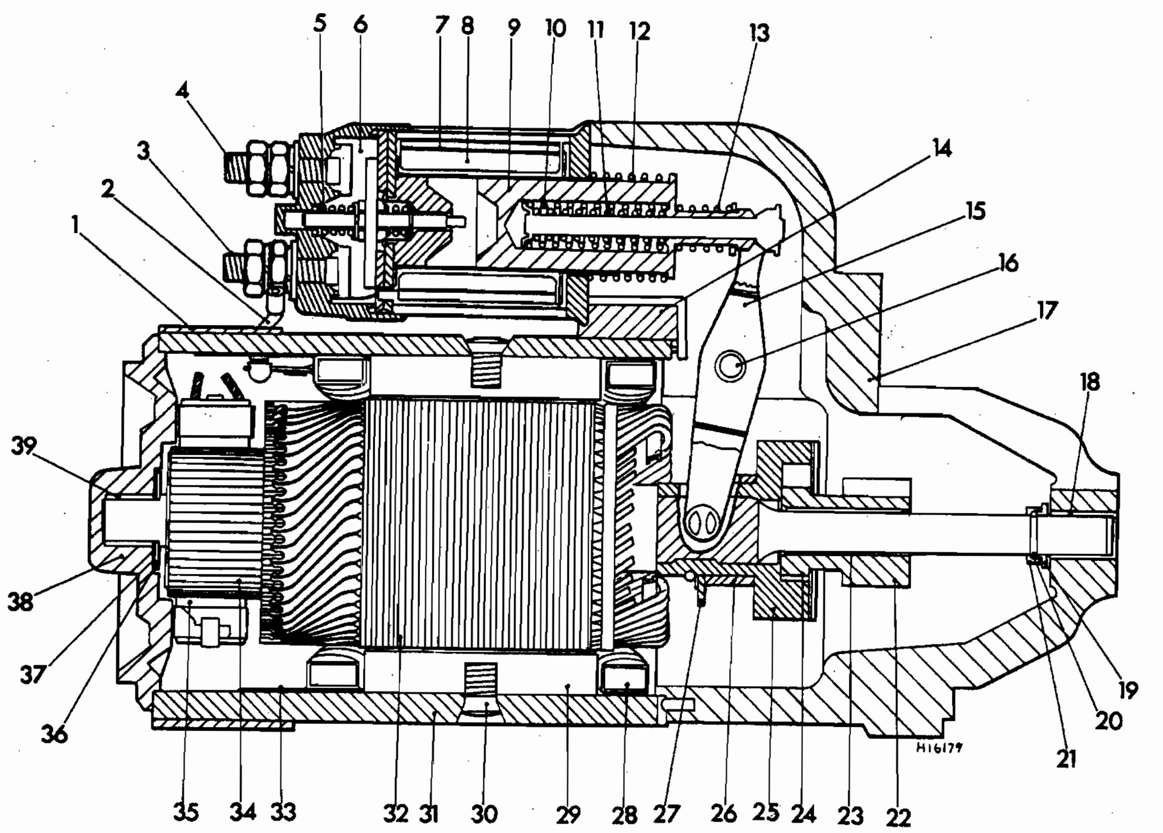

Fig. 10.5 Starter motor, Lucas type M418 pre-engaged – exploded view (Sec 27)

1 Cover band
2 Motor lead
3 STA terminal
4 Solenoid battery terminal
5 Contact assembly spring
6 Contact assembly
7 Hold-in winding
8 Pull-in winding
9 Plunger
10 Outer engaging spring
11 Inner engaging spring
12 Return spring
13 Lost motion spring
14 Rubber moulding
15 Engaging lever
16 Eccentric pin
17 Fixing bracket
18 Fixing bracket bearing bush
19 Thrust washer
20 Jump ring
21 Thrust collar starter drive
22 Pinion
23 Pinion bearing
24 Roller clutch action
25 Drive sleeve
26 Distance piece
27 Drive operating plate
28 Field winding
29 Pole shoe
30 Pole shoe screw
31 Yoke
32 Armature
33 Insulation strip
34 Commutator
35 Brush
36 Steel thrust washer
37 Fabric thrust washer
38 Commutator end bracket
39 Commutator end bracket bearing bush

QUESTION 2

Company XX has decided to market a new product: an electrically powered car jack. A design team is assembled to develop this product. A key constraint imposed by the team is that the jack must be powered by a standard cigarette lighter capable of delivering 12 volts through a 15 amp fuse.

a. Draw a function tree for the jack. Identify additional appropriate constraints.
b. Use the function tree, determined in part (a), to create a morphologic chart. Clearly show how you go from the "morph" chart to candidate designs.
c. Identify at least two designs and critically evaluate them using evaluation matrix methods. Clearly describe how you choose/weight your evaluation criteria.
d. For a scissors jack mechanism, discuss the work done by the jack during, say, one revolution of the screw. Do this for different jack configurations while the jack is lifting the car. Use your answer to explain the benefits to the powered jack design, if any, of this particular jack mechanism. *Do not attempt a detailed analysis of the screw jack.*
e. For a specific vehicle, it is determined that the maximum force required to lift one wheel off the ground is 600 pounds. At the same time, the jack must travel 18 inches to accomplish this task. Estimate the power required from the battery to lift the car at a uniform speed in 60 seconds. Will a fuse be blown or not?

If any part of this question is unclear, please state how you interpreted the question.

The pinion is not engaged with the flywheel if the engine is running. In fact, Fig. 10.5 shows the pinion in a disengaged position. When the car is started, electrical power through the solenoid battery terminal (item 4) induces a magnetic field in the hold-in and pull in windings (items 7 and 8) of the solenoid causing the iron plunger (item 9) to be pulled in (i.e., from right to left in Fig. 10.5). This causes the engaging lever (item 15) to rotate around the eccentric pin 16 and push the drive sleeve (item 15) and subsequently the pinion (item 22) outwards (i.e., to the right in your drawing) to engage the flywheel.

As shown in Fig. 10.5, the starter motor is equipped with various compression springs (items 5, 10, 11, 12, and 13). All springs have squared and ground ends. In the following, you will analyze the inner and outer engaging springs (items 10 and 11). **Questions a through d are focused on the inner and outer engaging springs** (items 10 and 11). Assume the following values for wire diameters (d), mean coil diameters (D) and total number of coils (N_{total}):

- The dimensions for the outer engaging spring (item 10)are d = 3 mm, D = 15 mm, N_{total} = 12
- The dimensions for the inner engaging spring (item 11) are d = 2 mm, D = 10 mm, N_{total} = 12
- Both are made of A228 music wire with a modulus of rigidity G = 79.3 GPa.

a) Calculate the force required to move the stem, i.e., compress the two springs, 23 mm.

b) Will the inner spring ever buckle? Why/why not?

c) If a designer would recommend two springs with the following dimensions:

Outer engaging spring: d = 3 mm, D = 12 mm, N_{total} = 12
Inner engaging spring: d = 2 mm, D = 10 mm, N_{total} = 12

Would this be a good recommendation? Why or why not?

d) Why should the inner and outer spring wires be wound alternatively left hand and right hand?

The following questions focus on the pinion gear (item 22). Assume that the pinion gear is a spur gear that has 9 teeth and a module m of 4 mm.

e) What are the pitch diameters of the pinion and the flywheel?

f) What is so special about an involute gear profile?

g) An engineer decides to use starter motor with a pinion that has a module of 4 mm with a flywheel that has a ring gear with a module of 5 mm. Is that a good idea or not? Why or why not?

h) Items 18, 23 and 39 are all bearing bushes. Give at least two reasons why the designers would have chosen these bearings over rolling element bearings.

Useful equations:

$$k = d^4 G / (8D^3 N_a)$$