A STRATEGY FOR TEACHING AND LEARNING OF SYSTEMATIC DESIGN ENGINEERING

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Abstract – Systematic engineering design can use the tools, models and methods recommend by Hubka to help designers, especially in critical situations. These methods can be applied for novel designing, or for re-designing. In teaching, observations of students revealed difficulties in applying and formulating “internal and cross-boundary functions” of technical systems (TS), and of “operations” in a transformation process (TrfP).

A strategy to overcome these difficulties is to introduce sufficient theory, then to provide a re-design problem, using an existing commercial device, (a) as a cut-away to show the inner workings, and (b) as a complete device that can be dis-assembled – accompanied by engineering drawings of each part, an assembly drawing and an exploded view. Students (1) studied the hardware and drawings, (2) identified elemental organs, and useful organ groups, and (3) wrote their interpretation of what each organ group is capable of doing – the TS-internal and/or cross-boundary functions, to be represented in a TS-function structure. An example is offered.

Keywords: Systematic engineering design, teaching/learning and since strategy, case examples

1. INTRODUCTION

Teaching and learning of engineering design has in the distant past been achieved by a form of apprenticeship – the master designed according to his experience and knowing, the apprentice assisted (usually in detailing) and learned by observation. Starting around the 1950’s, but more intensively since about the 1970’s, more formal design methods have been developed, especially in two directions: (1) an overall design methodology attempting to cover the whole engineering design process, typified by Pahl and Beitz [22], and by Hubka [16,17,20,21,28], and (2) a concentration on one or other aspect of the engineering design process to develop detail methods, often with emphasis on creativity [2], see Eder [9].

Hubka started to develop his approach around 1965, since then continuously developed [16,17] – based on a

theory of technical systems, what all TS have in common, logically presented. The most important models for this paper are (a) a model of a general transformation system,

Fig. 1. GENERAL MODEL OF A TRANSFORMATION SYSTEM [16,17,21].

Each technical system exhibits several structures, consisting of different kinds of elements, e.g. functions (Fu i), organs (Org i) and organ connectors (OrgC k), constructional parts (CP m) and their relationships.

Fig. 2. STRUCTURES OF TECHNICAL SYSTEMS (TS MODELS) [16,17,20,21].

see figure 1, and (b) a model of useful structures recognizable internal to and across the boundary of a technical system (an operator in figure 1), see figure 2.

This theory of technical systems forms the basis for deriving a voluntary and consistent systematic engineering design method(ology) that also allows use of any of the hundreds of detail methods [9]. Justification for this approach was given in [3], and direct connections and comparisons to some other approaches were established, e.g. [4].

Systematic engineering design, as understood in this paper, uses the Hubka approach to recommend tools, models and methods to help engineering designers, especially in critical situations. The recommended method can be applied for novel designing, or for re-designing. Case examples (22 to date) show applications of the method, including complex problems and re-designing.

The first case study, systematic according to the state of the theory and method at that time, appeared in 1976 [18] – a machine vice. The second appeared in 1980 [20] – a welding positioner. The next three, also systematic, were published in 1981 in German – a riveting fixture, a milling jig, and a powder-coating machine – the first two were systematic, the third took an industrial-artistic design approach. The third set was published in 1983 – a P-V-T-experiment, a hand winding machine for punched control tapes, and a tea brewing machine – again the first two were systematic, the third took an industrial-artistic design approach. An English edition was published in 1988 [19], and included the existing six case studies, plus two new items – a wave-powered bilge pump, and an oil drain valve – and again the bilge pump only loosely followed the systematic method. Three further case studies were published in 2008 [16] – the tea machine revised to current systematic procedures showing enhanced engineering information; re-design of a water valve [5]; and an electro-static smoke gas dust precipitator, with rapper for dust removal [6]. Three new case examples were published in 2010 [17] – a trapeze demonstration rig [7], re-design of an automotive oil pump [8], and a hospital emergency bed, with compensation devices for the support arrangement. Two other cases were prepared for the International Conference DESIGN 2012 [10,11], both from the Caravan Stage Barge [1] which has been in operation in Canadian and U.S.A. coastal waters, and now in the Mediterranean, since 1995. An RMC wind tunnel force balance accessory [12], and a Stage Barge gangway [13] were presented at CEEA2013. Stage barge life-boat davits [14] and a linear friction test research apparatus [15] will be presented in conferences during 2014.

Since 2010 [17], these case examples have been presented at the current latest stand of development of both the theory of technical systems, and the recommended systematic design process.

2. A TEACHING/LEARNING STRATEGY

In teaching these systematic engineering design methods at RMC, observations of students revealed that they found difficulties in applying and formulating concepts of “internal and cross-boundary functions” of technical systems (TS), and of “operations” in a transformation process (TrfP).

The best strategy to overcome these difficulties is to initially introduce sufficient theory by lecture or similar. This should especially cover the model of the transformation system, and the models of structures of technical systems – including detail consideration of the three main TS-internal and cross-boundary structures. As project work within the course, a simple re-design problem was introduced. Using an existing commercial device, (a) a cut-away was prepared to show the inner workings, and (b) a complete device that can be disassembled was supplied – accompanied by (reverse-engineered) engineering drawings of each constructional part, and including an assembly drawing and an exploded view. Two case examples are available, a water valve [5,16], and an automotive oil pump for engine lubrication [8,17] – which were used in alternate years. Students were first invited (1) to study the hardware and drawings, (2) to check for any faults found in the drawings, (3) to identify elemental organs, and useful organ groups, and (3) to state in writing their own interpretation of what each organ group is capable of doing – these are the ‘TS-internal and/or cross-boundary functions’, which the students are asked to represent in a TS-function structure. Students then were given a new requirement to be considered, asked to set up a (revised) design specification, and to alter their TS-function structure accordingly. They then applied a morphological matrix to explore a revised solution, proposed some revised TS-organ structures, selected the one that in their opinion was best, and sketched a proposed layout.

Having overcome the student difficulty of formulating TrfP-operations and TS-internal and cross-boundary functions, this step-by-step strategy allowed setting one or more follow-up novel design problems, passing through all available TrfP and TS structures. Several of the existing case examples were also presented to the students and discussed in class.

3. PARTIAL CASE EXAMPLE

Parts of the re-design case example “automotive oil pump for engine lubrication” [8,17] are offered here to show the typical results expected from the first project. The usual sub-headings for a re-design case are followed, with comments where needed. Two identical oil pumps from internal combustion engines dating to the 1970’s

were found. The body (part A) and cover (part E) were cast iron parts, machined. One was cut open for demonstration, the other was loosely assembled for students to take apart and handle. New detail and assembly drawings were prepared, for instance figure 3.

Fig. 3. OIL PUMP – ASSEMBLY SECTIONAL VIEWS AND PARTS LIST [8,17].

- (P1) Establish List of Requirements – investigate alter-natives
 - (P2) Establish a Plan for the Design Work – investi-gate alternatives
 - (P3a) Establish the Transformation Process – investi-gate alternatives (P3.1 – P3.1.4)
- See figure 4.

Fig. 4. OIL PUMP – TRANSFORMATION PROCESS [8,17].

For this initial project, these three design steps were deferred until the new requirement was introduced. Normally, a re-design problem does not include a

transformation process, it is only included here for clarity.

(P1Rev) Amend Design Specification for New Requirements:

- F Oil pump must be relocated outside of crank case.
- S Strainer and suction pipe remain inside crankcase / oil pan.
- F All parts must be easily accessible for repair.

PROCEDURAL NOTE: Step (P1Rev) has been placed here for the convenience of this paper, the students were informed about this step after they had completed their own TS-function structure for the given oil pump.

(PRev5) Establish the Existing TS-Organ Structure by Reverse Engineering

The revised design process starts from the existing assembly drawing, figure 3. This was first transformed into a 'skeleton' representation, ignoring all material thicknesses, see figure 5 – an organ structure. The revised boundary of the new TS(s) is also indicated.

Figure 13.11
Fig. 5. OIL PUMP – SKELETON (ORGAN) DIAGRAM OF CONSTRUCTIONAL STRUCTURE [8,17].

(PRev4) Establish the Existing TS-Function Structure by Reverse Engineering

By searching for significant contacts in both the assembly drawing or TS-constructional structure, and the TS-organ structure, figures 3 and 5, (a) between surfaces on adjoining constructional parts, (b) on constructional parts with the operand, and (c) with the active and reactive environment, elemental organs could be identified, together with their elemental functions, and organ groups.

PROCEDURAL NOTE: As a designer becomes more experienced, the typical organ structure of figure 5 is no longer as important, nor are the elemental organs – the organ groups can be 'read' directly from the TS-constructional structure.

Additional symbols needed:

- O – Oil operand (or air on start-up – Od1 and Od2 in figure 5)
X – Engine driving power supply
Y – Crankcase attachment flange

Const. Parts	Description Purpose (function verb)	Organ Group
<i>For the revised design specification, the following were no longer needed, they remain within the crankcase as constituent parts of the engine (Note that the above headings apply to all organs and/or organ groups):</i>		
O1-F	Oil in sump to pick_up collect and strain oil	
F-E	Oil pick-up to cover form guide for oil into cover	
<i>By inspection, the following were recognized as organs evoked by manufacturing requirements, they do not need to be considered for a revised TS-function structure, some of them may need to be re-considered in the new TS-constructural structure:</i>		
B1-D	Gear bore to drive shaft transmit driving torque, manufacturing auxiliary, press fit	
C-A	Idler axis to body manufacturing auxiliary, press fit	
E-L	Plug for transfer port manufacturing auxiliary, through drilling	
E-K	Plug for valve guide manufacturing auxiliary, through boring	
A-E	Cover to body seal against outward leakage	OGa
A-E-I	Cover to body fastening hold parts together	
<i>Connections to the fixed system 'engine' were found as:</i>		
A-Y	Body to crankcase attachment hold parts together	OG1
A-Y-O2	Body to crankcase oil channel allow transfer of pressurized air/oil	
O1-Y-A	Crankcase oil channel to body allow transfer of sucked oil	
D-X	Drive shaft slotted end accept torque and rotation	OG2

The organ grouping OG1 reflects the connection requirements for the revised oil pump. Elemental organs were selected to form the following two typical organ groups, and to formulate the appropriate functions – mainly as an educational demonstration exercise to show that elemental organs combine into useful groups:

A-B	Body flat bore face to gear face seal against back leakage	OG3
A-B	Body cylinder to gear tooth tip seal against back leakage	
E-B	Cover flat face to gear face seal against back leakage	
B1-B2	Gear tooth mesh seal against back leakage	
A-B-E	Gear tooth gap, flanks and root package oil for transport	
<i>The appropriate TS-functions for this organ group are:</i>		
	Fu1 “isolate a series of volumes that can be rotated from an input space to an output space”, and	
	Fu2 “adequately reduce back-leakage of oil”.	
J-E	Valve to cover guide seal against outward leakage	OG4
J-E	Valve to cover guide allow axial movement	
O2-J	Oil to valve head transform oil pressure to force	
J-E	Valve to cover transfer port open/close oil by-pass	
J-G	Valve to spring transfer axial force	
G-H	Spring to pin react spring force to cover	
H-E	Pin to cover retain valve and spring	
<i>The TS-functions for this organ group are:</i>		
	Fu3 “sense operand-space pressure”	
	Fu4 “move sensor proportionally to pressure”	
	Fu5 “at pressure limit, open by-pass port to allow operand into entry space”	
	Fu6 “seal against outward leakage”	
<i>The other organ groups were identified by inspection, without specifying the elemental organs:</i>		

X-D	Drive in engine to shaft end accept torque and rotation	OG5
D-B1	Shaft end to driving gear transmit torque and rotation	OG6
D-A	Driving gear shaft to body locate shaft in body	OG7
B1-B2	Driving gear to idler gear transmit tangential force and rotation	OG8
B2-C-A	locate idler in body	OG9
E-A	Cover to body transfer oil to gear mesh entry	OG10

TS-functions for these organ groups were formulated, the TS-function structure for the revised oil pump is shown in figure 6.

Figure 13.12

Fig. 6. OIL PUMP – FUNCTION STRUCTURE [8,17]

(P4) Establish the TS(s) – Organ Structure – investigate alternatives

Only three TS-functions need to be explored for alternatives, Fu12, and the groups of Fu3/Fu4/Fu5 and Fu11/Fu13, see figure 7. A formal morphological matrix is probably not needed, it would contain only three rows. Systematic sub-division of the appropriate concepts helped to make the survey as complete as practicable. The resulting organ structure is ready for a dimensional layout and detailing, see figure 8.

At the end of this project, students were given a copy of reference [8], and allowed to handle a loosely fitted sample of an aluminum-bodied Wankel-style [23] external oil pump as fitted by a notable manufacturer.

Figure 13.13
Fig. 7. OIL PUMP – PRINCIPLES OF OPERATION – MORPHOLOGY FOR FU12 AND FU3/FU4/FU5 [8,17,23]

Figure 13.14
Fig. 8. OIL PUMP – PROPOSED ORGAN STRUCTURE [8,17]

4. CLOSURE

This approach was found to be successful.

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