American Journal of Applied Sciences 2 (2): 514-525, 2005
ISSN 1546-9239

A Conceptual Design of the Concurrent Engineering Design System for Polymeric-Based Composite Automotive Pedals

S. M. Sapuan
Department of Mechanical and Manufacturing Engineering
Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

Abstract: In this study, a study of conceptual design for the polymeric-based composite automotive pedal box system is presented. This study describes the importance of the concurrent engineering technique in the total design activity. Several idea generation methods like the extension of the search space, the morphological chart, the exploitation of experiences, the gallery method and the voice of customer had been employed. Extensive application of the morphological charts enabled designers to identify the sub-solutions to each sub-functions of the pedal box system. The evaluation matrix method was used to decide on the final concept for the mounting bracket arrangement. The final solution for the polymeric-based composite pedal box system was three pedals mounted onto a common mounting bracket. The clutch and the brake pedals were pivoted onto a common shaft and the accelerator pedal had its own shaft. All the methods used were finally compared and evaluated.

Key words: Engineering technique, automotive pedals box system, conceptual design

INTRODUCTION

The automobiles have been manufactured since a century ogo. They were built in a tedious and laborious manner, with little mechanical assistance. However, later, the automotive industry has been developed with the help of modern technologies and methods. In this research, the development of a polymeric-based composite pedal box system is aided by advanced Information Technology (IT) tools such as solid modelling system, Knowledge Based System (KBS) and Finite Element Analysis (FEA) and well-respected methodologies such as total design (TD) and cost estimation within a Concurrent Engineering (CE) environment.

In the development of automotive components within a CE environment, activities like material selection, design and analysis, component specifications, customer experience, process selection and design modification play equally important roles for the successful development of a product as presented in 'CE wheel' in Fig. 1.

CE has been responsible for improvements in the automotive development process. The use of CE has resulted in numerous benefits including [1]:

* Involvement of all functions and personnel (including project engineers, designers, process engineers, cost analysts, marketing and sales personnel)
* Better processing considerations
* Improved manufacturing launch considerations
* Fewer revisions to the product after manufacturing has started (a very expensive procedure)
* Improved employee involvement and satisfaction
* Management involvement and acceptance

This research employs the total design (TD) methodology. Detail of this approach was described by [2]. He pointed out that if product design and process design are thought of as distinct serial activities and not carried out in parallel, then there would be delays in bringing new products to the market. Therefore, while using each total design activity, the designer should bear in mind that each activity is related to other activities and the order each is carried out is not fixed. The TD model is used because it provides a convenient way of tackling the design problem. Fig. 2 shows a new model for TD activity within the CE environment [3].

Conceptual design is a very important stage in TD process and this is the main issue in this study. Conventionally automobile pedals such as accelerator, brake and clutch pedals have been made of metallic materials and have been individually mounted in the automobile by means of metallic mounting brackets secured to the vehicle body, normally at the bulkhead. In general, the metallic material used was steel. The mounting brackets have been produced by presswork, drilling and welding. The use of metallic pedals and mounting brackets has added to the weight of the automobile. The manufacturing methods and their assembly in the automobile are time consuming and add to expense.

The proposed conceptual design stage addresses the use of various design methods in the design of polymeric-based composite pedal box system such as idea generation techniques (the gallery method, the voice of customer, and the extension of search space (Why? Why? Why?)), product design specifications (PDS), morphological charts and matrix evaluation chart in the early stage of design process. The focus of these methods is to enable designers to identify various design solutions and combinations of solutions available for the polymeric-based composite pedal box system. The methods attempt to identify the solutions by employing new ways of conceptual design and not just copying the methods available for metallic pedal box system.

The new concept of polymeric-based composite pedal box system consists of an accelerator, brake and clutch pedals mounted onto a common bracket. The brake and clutch pedals are assembled on a common shaft while accelerator pedal is attached to bracket by means of a small shaft. The brake and clutch pedals have the extension type springs, fixed to the top of pedals whereas the accelerator pedal employs an extension spring in the carburettor. A pair of gussets is attached to the mounting bracket. Between the gussets, protrusions are made for securing return springs and brake light switch.

The aim of this study is to describe the conceptual design stage of the development of polymeric-based composite automotive pedal box system. The conceptual design stage is a very important step in the design process. It forms the background work of the design of a pedal box system. The correct selection of concept design enables designers to develop a high quality product in the detail design stage. The architecture of the relationship between conceptual design stage activity with the rest of the design stages such as material selection, detail design and final product manufacture is shown in Fig. 3. The KBS for material selection of polymeric-based composite pedal box system was developed prior to this study and it was reported by [3, 4-10].

Product Design Specifications (PDS): In the early stages of conceptual design, the PDS of the polymeric-based composite automotive pedal box system was prepared. This approach has been used by the author [11-15] in the development of various engineering products. In these studies, the PDS were developed which formed as design guides and similar PDS is prepared in this study. The elements of PDS are shown in Fig. 4.

The design of automobiles and their components is nearly always evolutionary and does not change radically from one model or component to the next. In the PDS of polymeric-based composite pedal box system, many similarities are found between polymeric-based composite and that of metallic counterpart. The following are detailed descriptions of the elements of PDS:

Performance. All three pedals could be assembled onto a mounting bracket or one pedal to a bracket or two pedals in one bracket. The mounting bracket could in turn be secured to bulkhead of the automobile. The design should consider the method of pivoting pedals to the mounting bracket. This bracket could incorporate gussets to keep pedals in place. The automobile has pre-positioned bolts or bolt holes on the bulkhead to secure the pedal box system to an automobile. The mounting bracket could have holes or slots, where they could be fixed on the bulkhead of the automobile.

Reinforcing ribs and webs were designed at or between sections of pedals to reduce the weight and to withstand stresses applied to the pedals. The pedal box system must be resistant to wear and must have sufficient bearing strength. The design must consider possible failure due to fatigue, creep and shear.

The force on the brake pedal should be less than 2700 N with the maximum deflection of 15 mm [16]. The force on the clutch pedal must be less than 1000 N with the maximum deflection of 20 mm [17]. The force on the accelerator pedal must be less than 375 N with the maximum deflection of 10 mm [18]. The brake pedal must be depressed to apply the brakes and be capable of being depressed by the driver's foot.

The brake pedal must be fixed totally or partly to the right of the longitudinal axis of driver's seat. Actuation of one pedal must not be hindered by the depression of other pedals. The clutch pedal must be depressed to de-clutch and the final movement may also, when the facility is provided, apply as the brake. It must be capable of being depressed by the driver's left foot. Accelerator pedal depression must increase speed, when the automobile is in motion. Releasing the pedal must reduce the speed.

The accelerator pedal must be capable of being depressed for gentle and gradual acceleration or deceleration of automobile. By releasing all pedals, there must be automatic return to the original positions. This is achieved by means of springs or similar devices [19].

Environment: The pedal box system must be capable of use in all weather conditions and be corrosion resistant. It must be resistant to fuel spillage and degradation by ultraviolet radiation. The percentage of water absorption of the material must be less than 8 %.

Target Product Cost: The cost must include material, tooling, labour, and equipment costs. The total cost above must be less than the cost of manufacturing metallic pedal box system. The tooling cost must be less than £250 000 [20]. The direct material cost must be as low as possible (in this research the cost of £ 4.6 /kg is fixed but this could always be increased if the suitable material cannot be obtained at this price).

Size and Weight: In view of the limited space available for the driver's feet, the dimensions must be kept as small as possible. The length of all pedals must not exceed 0.5 meters.

Accelerator pedal weight: less than 260 grams
Clutch pedal weight: less than 500 grams
Brake pedal weight: less than 500 grams
Mounting bracket weight: less than 750 grams

MATERIALS AND METHODS

The material used for all components must be polymeric-based composite as this is the requirement for weight reduction purpose. However, the pedals, mounting bracket and other elements may involve some metallic reinforcement, moulded into them or applied after moulding.
Yield strength of the material for the accelerator pedal must be greater than 59.7 MPa, for the brake pedal greater than 211 MPa, for the clutch pedal greater than 136 MPa and for the mounting bracket greater than 25 MPa [3]. Modulus of elasticity of the material for the accelerator pedal must be greater than 5000 MPa, for the brake pedal greater than 14 000 MPa, for the clutch pedal greater than 9000 MPa and for the mounting bracket greater than 4000 MPa. Density of all materials used in all elements of the pedal box system should be lower than then density of aluminium, which has the density of 2.7 Mgm^{-3}. The Charpy impact strength of the material must be greater than 30 KJ/m^2. The material should be recyclable.
The following standards have been used in this research:

* BS 7178 - (British Standard Specification) Construction and layout of self propelled industrial trucks sit down rider-controlled.
* FMVSS 105 - (Federal Motor Vehicles Safety Standards) - USA test requirement on a passenger car brake system.
* ECE R13 - European test requirement on a passenger car brake system.
* ADR31- (Australian Design Rules) for a passenger car brake system.

Ergonomics: The distance between steering wheel and brake pedal must be kept to approximately 600 mm. The pedal design must not cause fatigue to the feet of the driver. The design must provide comfort and enough space installing and removal of the pedal box system. The pedal layout and construction must ensure a comfortable position for the driver. The design must take into account factors such as women wearing highly heeled shoes.

Patents: Consideration of possible patent infringement should be taken into account:

* DE 4122283, Plastic clutch pedal with cable holders of different sizes at different locations.
* DE 4226352, Plastic foot pedal (clutch pedal) for road vehicle.
* DE 4434254, Motor vehicle hydraulic clutch pedal and power cylinder.
* EP 0389684, Plastic pedal with hollow smooth walls of approximately equal thickness connecting pedal plate to lever.
* EP 4330600, Motor vehicle control pedals and their mountings.
* DE 4326183, Bearing block for pivotable bearing of coupling pedal.
* DE 4230150, Plastic bearing bush for foot pedal lever.
* EP 0431986 A1, Reinforced resin moulding used for steering column and pedal supports.
* EP 0433702A2, Spring mechanism for automobile pedal.
* DE 4301229, Operating device for vehicle clutch or braking system.

Safety: The component must be free from sharp edges. The system must comply with all relevant parts of the UK and International legislation. Pedals must not be too short to make it difficult for a driver to depress them in an emergency. They must be large enough to prevent the foot from slipping. The pedal pads must have enough treads to prevent slippage. The distances between pedals must not be too close. The clutch pedal needs to operate with as little force as possible to avoid the driver moving away from the seat.

Concept Development: When designing a pedal box system the designer must tackle the problem in a stepwise manner. These stages are interrelated and difficult to differentiate. Before a designer can start designing a pedal box system, he/she needs to have the following:

* Confidence that the component can be manufactured
* Knowledge of how it will be manufactured
* Knowledge of cost: materials, final components or subassemblies and capital equipment required
* Knowledge of the function of the pedal box system
* Knowledge of the restrictions placed on the pedal box system
* Knowledge of the kinds of materials that might be used and their properties

* Knowledge of the part dimensions and configurations
* Definition of component design requirements through a PDS
* Awareness of the need to obtain information from manufacturing engineers
* Knowledge whether or not this component could be put into production
* Need for verification of performance by finite element analysis technique
* Take into account the anisotropic properties of the material

At various stages of the TD process, various design methods have been discussed. [12, 21]. Some of these methods are appropriate in the conceptual stage of design. There are many methods available for initiation of concepts. The following are used in this research:

1. **Systematic Exploitation of Proven Ideas or of Experience:** [22] The analysis of existing systems is one way of initiating new or improved solutions. This analysis involves the mental or physical analysis of finished products. Existing products used for analysis could be:

* Competitors' products
* Older products of one's own company
* Similar products or assemblies in which several sub-functions or parts of the function structure correspond with those for which a solution is being sought

2. **Extending the Search Space. (Why? Why? Why?):** [23] A way of extending the search options is by asking questions 'why?' about the problem, e.g. 'why do we need clutch pedal?' 'Why cannot bracket be eliminated? Each answer must be followed up, with another "Why?' until a conclusion is reached or unexpected answer prompts an idea for a solution.

3. **Morphological Chart:[23, 24],** The purpose of this technique is to generate different arrangements and enable designers to choose new combinations of elements. The chart provides the range of elements, components or sub-solutions that can be combined together to form a solution. 'Morphology' means the study of shape or form, so a 'morphological analysis' is a systematic attempt to analyze the form that a product might take and a 'morphological chart' is a summary of this analysis.

4. **Gallery Method:** [25] The gallery method is a way to display a large number of concepts simultaneously for discussion. Sketches, usually one concept to a sheet are taped to the walls of the designers' room. Designers circulate and look at each point. They make suggestion for improving the concept or spontaneously generate related concepts.

5. **Voice of Customer:** [26] This is an important element of the quality function deployment (QFD) and it 'hears the voice of the customer' and is useful in idea generation phase. It provides information to other multidisciplinary experts to determine how best to deliver what the customer desires.

Accelerator Pedal Concept: Morphological chart method is used to generate alternatives for each function of the accelerator pedal. This chart is a grid of empty squares. On the left-hand side is listed the essential functions of the accelerator pedal. Then across each row of the chart is entered the appropriate means of achieving the functions. There is no relationship within the columns of the chart; the separate squares are simply convenient locations for the separate items. There might be, for instance, three means of achieving the first function, five means of achieving the second, two means of achieving the third, and so on.

When it is finished, the morphological chart contains the complete range of all the possible different solutions for the accelerator pedal. These solutions consist of the combinations made up by selecting one sub-solution at a time from each row.

The morphological chart of the accelerator pedal is shown in Fig. 5. The sub-functions identified are means of controlling pedal movement, pedal profile, ribbing pattern, pad attachment to pedal lever, pivot shaft location, means of connecting pedal to carburettor and pedal attachment to cable. For each sub-function between two and five solutions are generated. The combinations of final solutions are circled. The final concept is a pedal controlled by an extension return spring hooked to the carburettor, with a "V" ribbing pattern. The pad is an integral part of the pedal lever. The pedal is mounted to the bulkhead by means of a small shaft enclosed by a pair of anchorage. The throttle cable is used to link the pedal and the carburettor. This is a logical choice and based on conventional designs.

Brake Pedal Concept: The functions selected for the brake pedal are almost the same as that of the

accelerator pedal. Factors like pedal connection to the brake disc, access to connection of pedal to the hydraulic cylinder, pivot shaft location and the type of brake signal are also considered. Similarly, between two and five solutions are generated and finally combinations of solutions one from each function are chosen for the final concept. The concepts are indicated using circles in Fig. 6. These concepts come up with a pedal controlled by an extension return spring, attached from the top of the pedal to the bracket gusset. The pedal is connected to a brake disc by means of a hydraulic cylinder, fixed to the pedal from the bottom of the pedal. The common pivot shaft is located at the far end of the pedal. Ribbing pattern of the "V" shaped pedal lever is chosen and pedal pad is an integral part of the pedal lever. The brake pedal light switch is situated on top of the pedal. This is a logical choice and based on conventional designs.

Clutch Pedal Concept: For the clutch pedal, similar functions to the accelerator and brake pedals are used, as all these components are similar in terms of operation and shape. The morphological chart of the clutch pedal is shown in Fig. 7. The clutch pedal is controlled by means of an extension return spring from the top of pedal. The pedal is linked to the clutch using a cable. This cable is attached to the pedal end by means of a hook designed for this purpose at the end of pedal. Similarly, the pad is attached to the pedal as part of the pedal with a "V" ribbing pattern, "I" profile and the pivot shaft located at some distance from the pedal end. This is a logical choice and based on conventional designs.

Mounting Bracket Arrangement Concept: Six different concepts of mounting bracket arrangement for the accelerator, clutch and brake pedals are considered in this design. Most of these arrangements follow the design of metallic mounting brackets developed by various car manufacturers. For a polymeric-based composite mounting bracket arrangement, the design is quite similar so their concepts are chosen.

Concept 1: This has no bracket but employs a horizontal shaft where all pedals are pivoted at one end to it so that pedals could be depressed at the other end. This shaft is attached directly to bulkhead.

Concept 2: ABC bracket. Accelerator, clutch and brake pedals mounted on a common bracket but have different shafts.

Concept 3: BC bracket. Clutch and brake pedals mounted on a common bracket and pivoted on a common shaft, accelerator pedal is pivoted to its own shaft and in turn is mounted onto the common mounting bracket.

Concept 4: AB bracket: The accelerator and brake pedals have common brackets but a separate bracket for the clutch pedal.

Concept 5: BC bracket. Brake and clutch pedals have a common bracket but have a different shaft and the accelerator pedal is connected directly to bulkhead by means of a small bracket.

Concept 6: A, B and C brackets. The accelerator, brake and clutch pedals have different brackets and shafts. These brackets are connected to bulkhead (Fig. 8).

Evaluating Alternatives of Mounting Bracket Using Weighted Objective Method. The evaluation of alternatives for the mounting bracket arrangement was carried out using the weighted objectives method. This method provides a means of assessing and comparing alternative designs, using differentially weighted objectives. This method assigns numerical weights to objectives, and numerical scores to the performances of alternative designs measured against these objectives [23, 27].
The calculation of utility values for 6 different concepts of mounting bracket arrangement is shown in Table 1. Given that all 6 concepts are workable and within the targeted cost, the following objectives are set:

* Low cost
* Maximum benefit of a low load in accelerator pedal
* Manufacturability
* Low amount of material use
* Low weight
* Few parts

These are considered to have the respective relative weight of 0.25, 0.2, 0.1, 0.1, 0.25 and 0.1. These figures were decided during the brainstorming session carried out in the concurrent engineering laboratory. All the concepts are assigned with values using nine-point-scale. For each alternative, the utility score for each objective is multiplied by the objective weight giving a relative utility value. If these are added together an overall utility value for each alternative is obtained. As the value in Table 1 show, Concept 3 was the best overall. This concept of the mounting bracket is the 'BC' bracket arrangement. The brake and clutch pedals are pivoted in a common shaft in the mounting bracket. The accelerator pedal is pivoted to its own shaft, which in turn mounted on the common mounting bracket.

Mounting Bracket Final Concept: Although the arrangement of the mounting bracket has been decided, the final concept has not been developed yet. In this

Table 1: Evaluation Matrix of Mounting Bracket

Objectives	Weight	Concept 1 Score Value		Concept 2		Concept 3		Concept 4		Concept 5		Concept 6	
		S	V	S	V	S	V	S	V	S	V	S	V
Low Cost	0.25	4	1	9	2	2.25	7	1.75	5	3	0.75	1	0.25
Max. use of Low Load in Gas pedal	0.2	1	0.2	6	1.2	6	1.2	9	1.8	6	1.2	9	1.8
Manufactur-Ability	0.1	9	0.9	5	0.5	7	0.7	4	0.4	3	0.3	1	0.1
Material Utilization	0.1	9	0.9	1	0.1	7	0.7	5	0.5	3	0.3	4	0.4
Low weight	0.25	4	1	5	1.25	9	2.25	7	1.75	3	0.75	1	0.1
Number of Parts	0.1	9	0.9	3	0.3	5	0.5	3	0.3	1	5	1	0.1
Overall Utility Value		4.9		5.6		7.1		6		3.4		2.9	

Table 2: Comparison and Evaluation of Methods Used

Methods	Used in/as	Extent of use
CE	Philosophy	Throughout the study
TD	Platform	Throughout the study
PDS	Specifications	Very extensively used during specification stage
Exploitation of provent ideas	Concept Generation	Fairly extensively used to generate ideas
Extension of Search Space	Concept Generation	Only some time used
Morphological chart	Concept generation	Used for all components
Gallery method	Concept generation	Only sometimes used
Voice of customers	Concept generation	Only sometimes used
Matrix evaluation	Concept evaluation	To evaluate mounting bracket abrangement concept
Solid Modeling	Final concept	Used after final design was selected

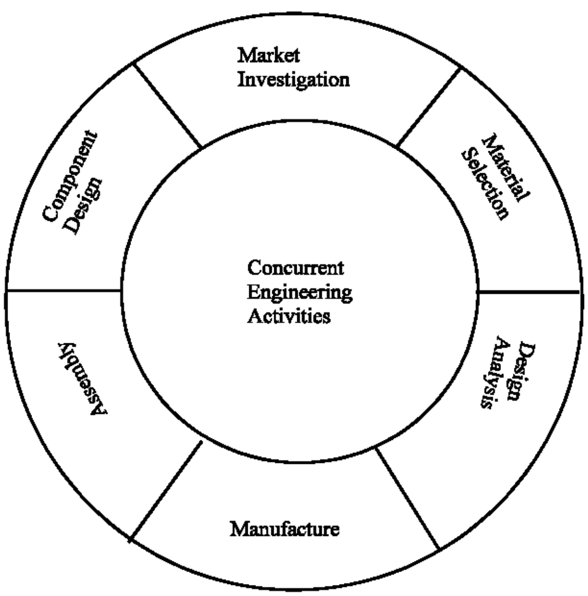

Fig. 1: CE Wheel

section, a morphological chart was once again used for this purpose and it is depicted in Fig. 9. The sub-functions identified for the mounting bracket include bracket orientation to bulkhead and/or floor, clutch pedal placement, type of brake/clutch pedal bracket gusset, strengthening mechanism, clutch/brake pedal gusset design, means of attachment to bulkhead or floor and finally the accelerator pedal gusset design. Between two and four solutions are generated for the sub-functions and the final concept is decided upon using the method similar to the previous charts.

The final concept consisted of a mounting bracket, which was vertically mounted to the bulkhead. A pair of bracket gussets was made for both clutch and brake pedals. Manufacturing separate gussets and mounting bracket were not needed as they are made using the same mould. Four holes were provided in the bracket, as the provision for nuts and bolts needed to install the pedal box system to the bulkhead. These holes were located at each corner of the mounting bracket. Additional holes were also provided for access to the hydraulic cylinder of the brake pedal and cable linking

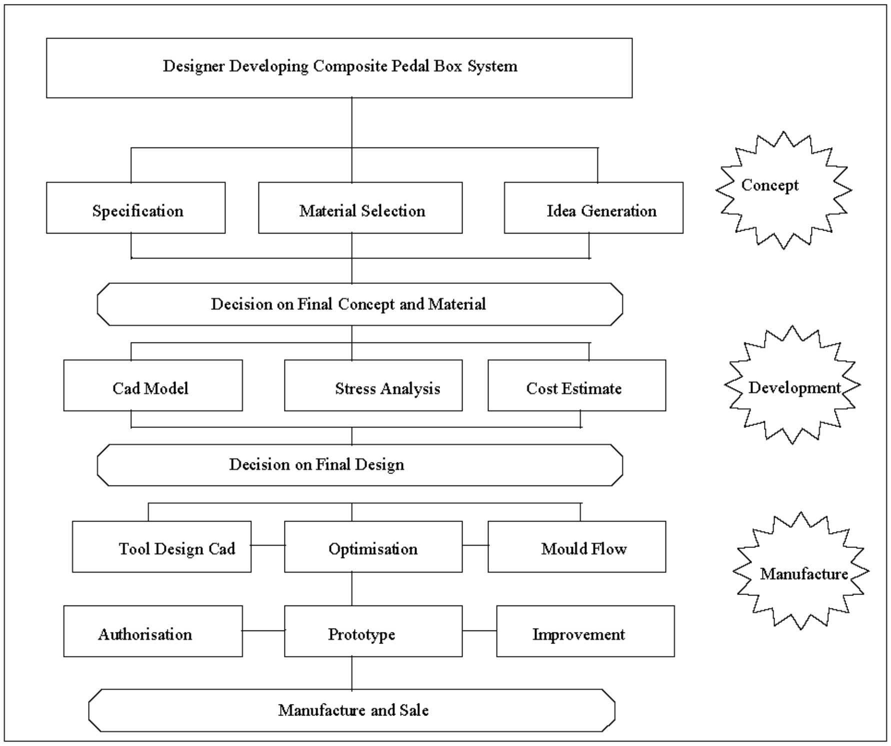

Fig. 2: New Design Method

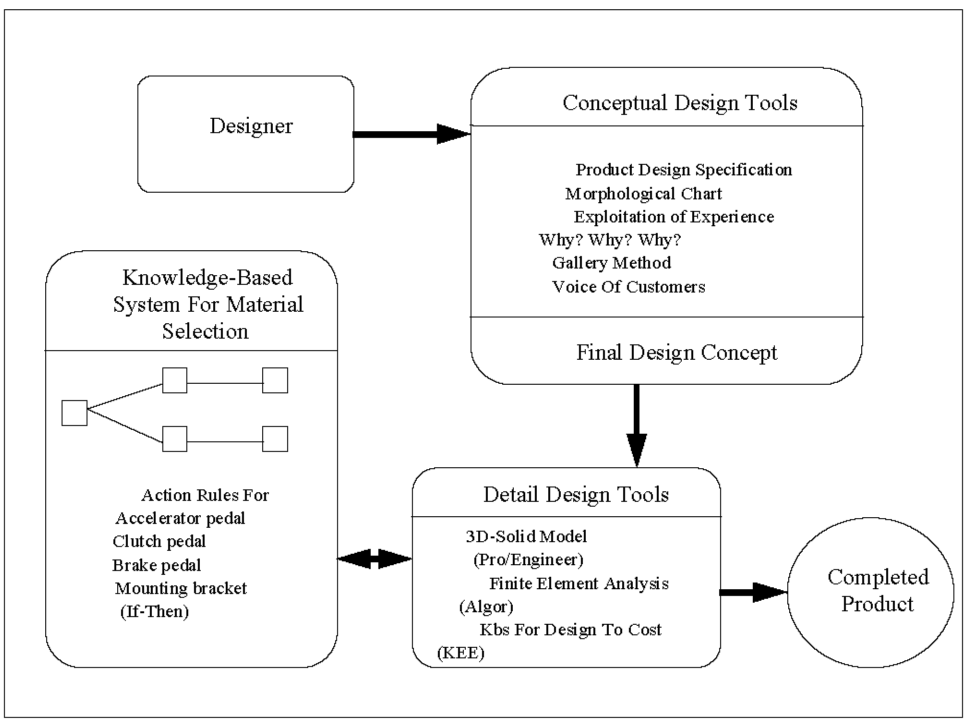

Fig. 3: The Link between Conceptual Designs to Other Design Process Activities

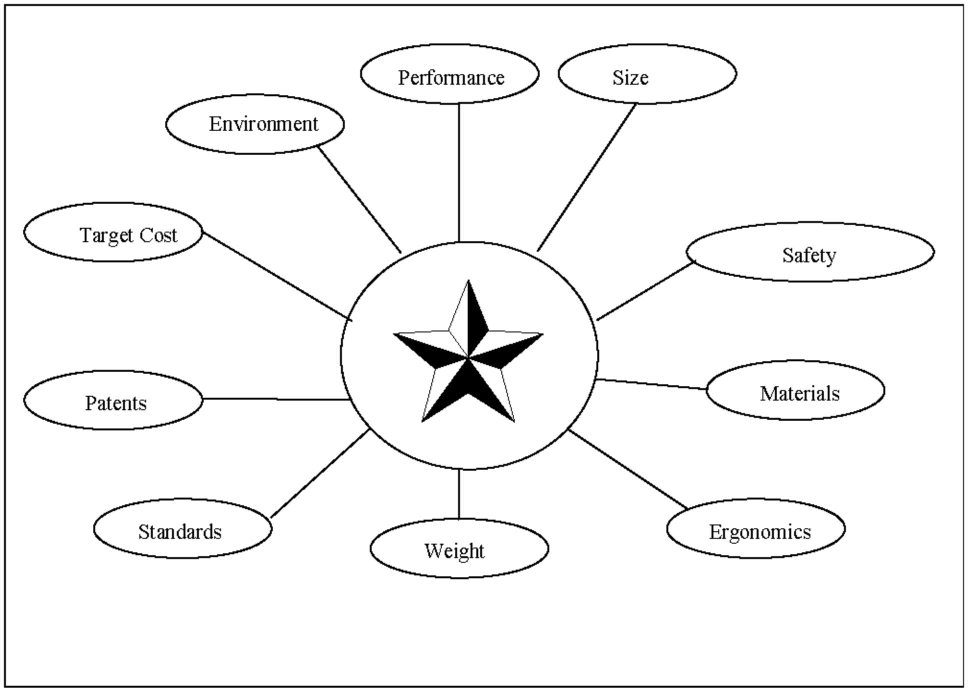

Fig. 4: Elements of PDS

SUBFUNCTION \ SOLUTION		1	2	3	4	5
1	MEANS OF CONTROL-LING PEDAL MOVEMENT	Extension spring	Compression spring	Torsion spring	Hydraulic system	Spring in carburet tor
2	PEDAL CON-NECTION TO CARBURET-TOR	Hydraulic cylinder	Cable			
3	PEDAL ATTACHMENT TO CABLE OR CYLINDER	Shaft	Single slot	Double slot	Clevis pin	
4	PEDAL PAD DESIGN	Integral with pedal	Design separately then attached			
5	PEDAL PROFILE	I	U	O	C	H
6	RIBBING PATTERN	V	X	No ribbing	2 rows of V	2 rows of X
7	PIVOT SHAFT LOCATION	End of pedal	Along pedal lever			

Fig. 5: Morphological Chart of Accelerator Pedal

	SOLUTION / SUBFUNCTION	1	2	3	4	5
1	MEANS OF CONTROLLING PEDAL MOVEMENT	Extension spring	Compression spring	Torsion spring	Hydraulic system	
2	PEDAL CON-NECTION TO BRAKE	Hydrau-lic cylin-der	Cable			
3	PEDAL ATTACHMENT TO CABLE OR CYLINDER	Shaft	Single slot	Double slot	Clevis pin	
4	BRAKE SIGNAL	Sensor	Light switch			
5	PEDAL PROFILE	I	U	O	C	H
6	RIBBING PATTERN	V	X	No ribbing	2 rows of V	2 rows of X
7	PIVOT SHAFT LOCATION	End of pedal	Along pedal lever			

Fig. 6: Morphological Chart of Break Pedal

	Solution / Subfunction	1	2	3	4	5
1	Means of Controlling Pedal Movement	Extension spring	compression spring	Torsion spring	Hydraulic system	
2	Pedal Con-nection to Clutch	Hydraulic cylinder	Cable			
3	Pedal Attachement To cable or Cylinder	Shaft	Single slot	Double slot	Clevis pin	
4	Padal Pad	Integral with Pedal	Separately Made than attached			
5	Pedal Profile	I	U	O	C	H
6	Ribbing Pattern	V	X	No ribbing	2 rows of V	2 rows of X
7	Pivot Shaft Location	End of pedal	Along pedal lever			

Fig. 7: Morphological Chart of Clutch Pedal

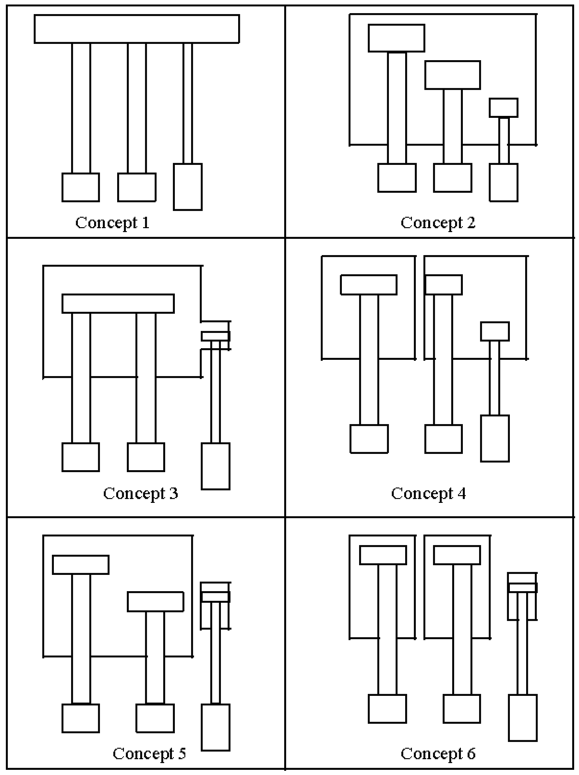

Fig. 8: Mounting Bracket Concept

	SUBFUNCTION \ SOLUTION	1	2	3	4
1	BRACKET ORIENTATION TO BULKHEAD/ FLOOR	vertically mounted	At 45 deg. from floor	At 45 deg. but from top	Mounted to the floor
2	CLUTCH PEDAL PLACEMENT	Outside gusset of brake pedal	Gusset enclosed clutch/ brake pedal		
3	BRAKE/ CLUTCH PEDAL GUSSET TYPE	A pair on both sides	Side and top gusset		
4	STRENGTHEN ING MECHA- NISM	Ribbing	Metal reinforce ment	None	
5	CLUTCH/ BRAKE PEDALGUSSET DESIGN	Separate ly design	Integral with bracket		
6	MEANS OF SECURING TO BULKHEAD/ FLOOR	Holes in bracket and bulkhead (and floor) for nuts and bolts	Bolts built in bulkhead (and floor) and holes in bracket	Bolts built in the bracket	Holes and bolts in bracket
7	ACCELERA- TOR PEDAL GUSSET DESIGN	A pair on both sides	Side and top gusset		

Fig. 9: Morphological Chart of Mounting Bracket

American Journal of Applied Sciences 2 (2): 514-525, 2005
ISSN 1546-9239

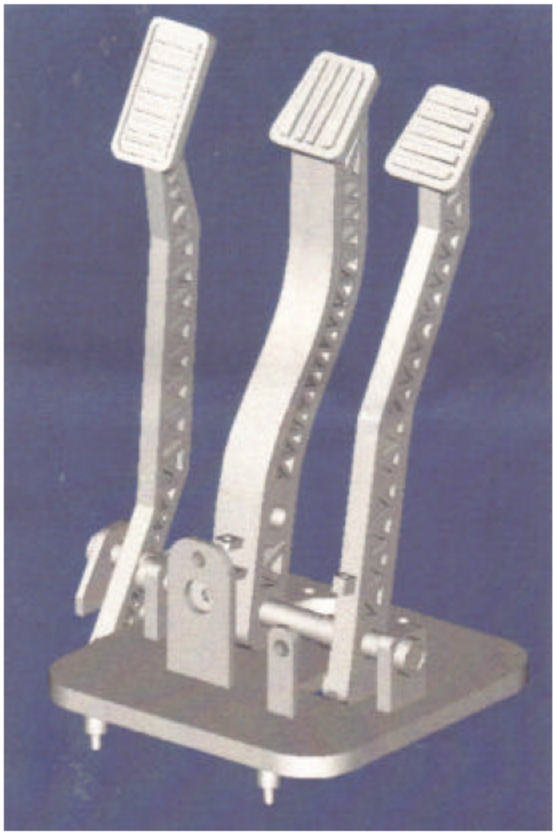

Fig. 10: 3-D Model of Final Concept of Polymeric Based Composite Pedal Box System

3 dimensional form using a CAD system. The concept for clutch pedal developed using 3 D CAD system is shown in Fig. 10. The final concept consisted of an accelerator, brake and clutch pedals mounted onto a common bracket. The brake and clutch pedals were assembled on a common shaft while the accelerator pedal was attached to the bracket by means of a small shaft. The brake and clutch pedals had the extension type springs fixed to the top of pedals whereas the accelerator pedal employed an extension spring in the carburettor. A pair of gussets was attached to the mounting bracket. Between the gussets, protrusions were made for securing return springs and brake light switch.

The mounting bracket was mounted to the bulkhead vertically by means of several bolts and nuts. Two holes were made on the base of the bracket for access to the hydraulic cylinder in the brake pedal and the cable clutch in the clutch pedal. The slot for the former was circular and bigger than the latter, which was rectangular. "V" shaped ribbings were provided on each vertical sides of the pedals.

Evaluation and Comparison of the Methods Used: The design methods used in this study include the PDS, the exploitation of the existing ideas, the CE, the TD, extension of the search space, the gallery method, the voice of customers, the morphological chart, the concept evaluation matrix and solid modelling system.

The CE method was mainly used as the philosophy of the study where the idea of integrating the design and manufacture during the early stage of the design process was emphasized. In carrying out this method, other methods and techniques were used as the concurrent engineering tools.

The TD acted as the platform for the study. The TD method describes each stage to be undertaken during the design process, beginning from the market investigation, followed by the conceptual design, the detail design, manufacture, sale and disposal. The rest of the methods are used at each stage of the TD design process, for instance the gallery method is used during the conceptual design and the matrix evaluation method is used during the concept evaluation stage. Table 2 shows the methods used in the study, where they were used and at what extent they were used in this study.

CONCLUSION

The methods of TD and CE were very useful for the design of polymeric-based composite pedal box system.

The final design was a pedal box system assembled onto a common mounting bracket.

The preparation of an extensive PDS helped the designer to design a pedal box system where at each stage, the designer can always refer back so that the design was within the acceptable specifications.

The extensive use of morphological chart enabled designers to identify various sub-solutions of some function of pedals. Various methods for generating ideas have been used in this study and they proved to be useful.

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