Original Article

Conceptual design of creep testing rig for full-scale cross arm using TRIZ-Morphological chart-analytic network process technique

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A B S T R A C T

Cross arm is the main component used to lift the electric cable in a transmission tower. Recently, a synthetic cross arm was proposed to substitute the wooden cross arm due to the extreme creep deformation, which can induce a structural collapse. Several creep studies were conducted on a coupon scale for the synthetic cross arm. However, there is a lack of study on the assessment of creep properties for the actual size cross arm. Thus, the development of a special rig is required to accommodate the creep test. The paper explains the development of creep testing rig for a full-scale cross arm using the integration of theory of inventive problem solving (TRIZ), morphological chart, and analytic network process (ANP). In the beginning, the finding of principle solutions was conducted using the TRIZ contradiction matrix. The characterisation of the design concepts was elaborated using the morphological chart. Finally, the ANP principle was exploited to select the best design via the pairwise comparison technique. The results show that Concept Design 5 (hybrid bracing design) scored the highest value and ranked first. Lastly, challenges on the design of creep testing machine and the improving criteria in concurrent engineering is presented.

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1. Introduction

Conceptual design is one of the most critical early stages in a product development to acquire the design goals and product specification [1]. In 1963, Chengal wood (Neobalanocarpus heimii) cross arm was installed in a 132 kV transmission tower after the successful adaptation on a 66 kV tower in 1929 [2]. The wooden cross arm was selected because of its outstanding performance in mechanical properties and lightning arch quenching [3]. However, the matured Chengal wood displayed an extreme deformation during its service in the late 1990s.

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More studies show that most of the old wooden cross arm started to fail after 24 years of service due to ageing [4]. A failure might be induced when a wooden cross arm is operated within 14 years of service [5]. This observation happened was due to natural fibre and wood defects since the wood was exposed to constant loading in a prolonged time [5–13]. Thus, there is an urgency in finding alternatives for the wooden cross arm to solve the issue according to the previous reports. To fulfil the requirements in finding the alternatives, glass fibre reinforced polymer (GFRP) composite cross arm was introduced in transmission towers to replace the current cross arm used [14–16].

Many numerical simulations were conducted to obtain the technical data for the mechanical properties of composite cross arms. Many previous researchers have conducted the computational simulation analysis of cross arm including its influence on stacking sequence of a laminate [17], static loading [18], and laminate properties on its failure [18]. Despite that, several experimental studies were performed on a coupon scale to examine the long-term deformation behaviour. To be specific, the coupon testing was executed in three-point bending mode [19], four-point bending mode [20], and tensile mode [21] to predict the creep life of the GFRP material. Hence, the coupon test aids the researchers to characterise the mechanical properties of the GFRP material when exposed to long-term loadings.

Despite many discussions done on the numerical simulations and coupon testing, there is still few study on the evaluation of creep behaviours (long term deformation) for a full-scale composite cross arm. Furthermore, the composite cross arm is still comparatively new to the market compared to wood and steel, and its service life in transmission towers is yet to be fully explored and discovered [22,23]. In this case, it is necessary to perform a long-term mechanical testing on the actual scale of the composite cross arm used in the transmission tower to predict the structure’s lifespan. Hence, a new creep testing rig was developed to accommodate the actual size of the cross arm to study the creep properties of the structure.

Performing creep analysis on a full-scale product can eliminate various exaggerated factors used in designing structures at a lower scale. Furthermore, product geometry and material profile may be ignored in these coupon tests. Therefore, to fully understand the creep properties and obtain a more reliable prediction of the composite cross arm’s service life, tests on an actual sized structure are highly crucial. In a test rig, various mechanical analyses that used an actual sized composite cross arm are needed to be conducted [24]. The study of creep for each member component of the cross arm will provide a more intuitive and holistic view in predicting the creep behaviour of the whole structure.

In the designing stage, the design must be developed using a proper dimension without compromising the strength and reliability of the product. It is crucial to consider the rigidity in the structure as well as the strength and geometry in its bracing system [25]. In general, the overall conceptual design is divided into concept generation, concept clarification, concept selection, and concept development [26]. A proper design is beneficial to design a complex shape with better strength and structural integrity to cater to the actual size of the cross arm during the creep testing [27]. From the statement above, the durability and design of creep testing rig need to be improved.

In this end, a conceptual design of creep testing rig was developed. The establishment of creep testing rig concept design allows the load–time based creep test can be performed to identify the creep performance in each of cross arm members. Due to the research requirement, the established engineering approach from the integration of TRIZ, morphological chart approach, and ANP methods was used to develop the conceptual design of the creep testing rig. In the conceptual design, four stages were defined including idea generation [28], idea refinement [29], concept design development [30], and concept design selection [31] using the mentioned methods. At the end of the development process, five new design concepts were created, and the best design was chosen according to the specification of the product design.

2. Applications of TRIZ in concurrent engineering for new product development

TRIZ is a useful method originated from Russia which was established in 1946 by G. Altshuller. The method is very beneficial to achieve excellent engineering and science ideas from the process of root to find alternatives and solutions [32]. The systemic approach in TRIZ aims engineers and scientists to place any concession between the gaps in product design and develop better outcomes for future technologies and products with lesser risk. Commonly, there are four specific approaches that can be selected in solving a problem using the TRIZ method from 39 engineering parameters and 40 inventive principles depending on the contribution level of the problem [33]. The TRIZ method has its specific benefit primarily as a diagnostic medium to provide a series of actions with freedom and modern approach to deal with issues via various brainstorming innovative programme repeatedly impromptu with decision depending on luck. Using the expert system software also proved to be faster, more interactive, and useful in the material selection process [34].

The applications of TRIZ-morphological chart-ANP method to develop a product are gaining attention as reported by many researchers. The approach is beneficial to accommodate the needs and accomplish goals to produce better product design. Besides, it provides a systematic opportunity identification and an innovative approach to address the problem with the suitable design [35]. The TRIZ method is very useful to generate ideas to solve the identified issues [36]. In the meantime, the morphological chart is one of the evaluation methods to enhance the generated ideas from the TRIZ inventive solutions [37]. Apart from that, the ANP approach is essential to select a suitable conceptual design to develop the new creep testing rig for a full-scale cross arm [38].

For instance, the integration of TRIZ with ANP in developing an engine rubber mounting composite is one of the TRIZ principle applications [39]. In the application, four conceptual designs were developed and a suitable design was selected for the engine rubber mounting from kenaf fibre polymer composite using the ANP method. Other than that, the selection of design for door panel is one the examples of TRIZ and ANP integration [40]. On the other hand, ANP and technique
Table 1 – Review of the application of TRIZ-Morphological Chart-ANP and related concurrent engineering approaches for product development.

<table>
<thead>
<tr>
<th>Application of TRIZ</th>
<th>Product development example</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRIZ, Morphological Chart, AHP</td>
<td>Automotive parking brake lever</td>
<td>[35]</td>
</tr>
<tr>
<td></td>
<td>Automobile engine rubber composite</td>
<td>[39]</td>
</tr>
<tr>
<td></td>
<td>Automotive spoiler</td>
<td>[42]</td>
</tr>
<tr>
<td></td>
<td>Automotive door panel</td>
<td>[46]</td>
</tr>
<tr>
<td></td>
<td>Composite shoe shelf</td>
<td>[43]</td>
</tr>
<tr>
<td></td>
<td>Composite automotive anti-roll bar</td>
<td>[44]</td>
</tr>
<tr>
<td>TRIZ, ANP</td>
<td>Dual layer tread tire</td>
<td>[45]</td>
</tr>
<tr>
<td></td>
<td>Automated communication connector</td>
<td>[46]</td>
</tr>
<tr>
<td>TRIZ, ANP, Eco-Design elements</td>
<td>Bottle casing</td>
<td>[36]</td>
</tr>
<tr>
<td>TRIZ, ANP, ECQFD</td>
<td>Overflow valve</td>
<td>[47]</td>
</tr>
</tbody>
</table>

![Fig. 1 – Schematic diagram of cantilever beam installed with LVDT [48].](image)

for order preference by similarity to ideal solution (TOPSIS) are commonly applied in the conceptual design selection for product development [1,41]. These methods are crucial in the decision-making process where multiple proposed attributes and design alternatives are analysed simultaneously. These selection techniques are suitable for targeted design specification and can be implemented in a combination selection process. Table 1 summarises the past application of TRIZ-morphological chart-ANP and related concurrent engineering approaches for product development.

3. Case study for a new product development: creep testing rig for full-scale cross arm

Generally, a cantilever beam testing is usually conducted on a small scale in the laboratory to measure the deflection behaviour of an extended beam structure as shown in Fig. 1 [48]. This product mostly made by using a simple fixed at one end while the other side is free, which the loadings are used to be implemented. In this study, the same concept was applied to the cross arm structure to study the deflection behaviour at constant load during an extended period. However, there is no actual testing rig available in the market to test this transmission component since it has not been developed yet.

Most of the transmission towers are designed and fabricated in the form of lattice steel structure in transmitting high voltage current to the consumer [49]. In the past few decades, the latticed steel transmission tower was used in the transmission grid due to better mechanical strength and greater structural integrity. The transmission tower was made up of steel frame with truss system where the angled members supported compression and tension loads. Other literatures also stated that the height of transmission towers, especially for 132 kV towers is generally between 60 and 100 m [50–52]. Usually, the transmission tower has heavy weight since it supports heavy electrical cables and other external loads. The researchers were asked to construct a piece of testing equipment for a full-scale cross arm, with the scale following the length and width of the existing 132 kV transmission tower. In this project, a creep testing rig to equip the full-scale cross arm in a 132 kV transmission tower was developed.

3.1 Integration strategy of TRIZ-Morphological Chart-ANP model to develop product design

In the study, the development of the creep testing rig design was based on the integration of TRIZ, morphological chart, and ANP. The method was employed to explore the suitable solution for the problem, especially in the conceptual design stage. In the hybrid approach, the TRIZ method was implemented to provide solutions to identify problems and generate ideas. Meanwhile, the morphological chart was equipped to refine the generated ideas based on TRIZ recommended solutions. Lastly, the ANP approach was applied to select the best concept design to develop the new creep testing rig for a full-scale size cross arm. Fig. 2 depicts the general concurrent engineering design approach using the integration of TRIZ, morphological chart, and ANP method.

3.2 Defining the design goals and identifying the improving and worsening parameter of engineering system

From the identified problem, an engineering solution using the TRIZ method was implemented. First, the engineering worsening problem and improvement constraints were determined using the TRIZ contradiction matrix method. The obtained contradiction matrix was summarised to classify the product that needs to be improved according to the worsening conditions as shown in Table 2. Then, the suitable TRIZ solution method was identified to suit the conceptual design of creep testing rig.
In this research, the primary design intent to replace the standard small scale of cantilever beam testing rig to a larger size which can occupy a full-scale cross arm. Subsequently, higher stability and structural integrity of the testing rig can be entirely operated.

3.3. Implementing the problems using the 39 engineering parameter and identify the appropriate TRIZ solution principle using contradiction matrix

Table 2 shows the improving and worsening features of the current design based on the possible contradiction in the TRIZ 39 engineering parameters. The goal of this step is to visualise the contradiction matrix between the improvement and worsening parameters. Hence, the solution was identified using the TRIZ 40 inventive principle technique as depicted in Table 3.

3.4. Developing design solutions based on 40 inventive principle method

Table 2, and the best principles were nominated as a guideline to improve the new engine creep testing rig concept designs. To achieve the new design, the #6 universality and changing the degree of flexibility in the #35 parameter changes along with #1 segmentation, the reliability of the creep testing rig should not be compromised. Hence, Table 3 summarises the design strategy based on the identified TRIZ solution.

3.5. Redefining selected solution principles into relevant alternative design components or system elements

The solution was obtained from the TRIZ inventive principles by implementing the morphological chart technique and translated into appropriate alternative system elements. Mostly, it was created depending on its usage to deliver ideas in the form of characteristics with the idea generation process [39]. Additionally, the morphological chart aids in the classification of sub-solution and sub-function of the design models created. Thus, a network of individual design solutions which linked every function can be created and installed in the new product design solution [27].

The refining in design solutions in the morphological chart can further enhance the selected TRIZ inventive solutions into design specifications and characteristics. As mentioned earlier, the TRIZ solution is abstract, which cannot be explained by the design specification. Thus, a requirement of following clarification is vital to convert the general solution statement into particular design features. Subsequently, design developers can identify and create specific design concepts based on the idea refined from the morphological chart step. In the end, the successive deployment of TRIZ inventive technique is significantly contributed to picture the image with specific characteristics based on the proposed solutions.

According to the general design of cantilever creep testing rig available in the market, the equipment should accommodate the strain measuring hardware with durable loading capacity, fixed mounting, and varied equipment size. Fig. 3 shows the sample of a standard specification for the small-scale cantilever beam's creep testing rig. Based on this feature, a selection using the morphological chart was made to narrow down the criteria of selection. Based on Fig. 4, the selection was made by either the designer's interest or creativity. Therefore, the integration of TRIZ and morphological chart approach helps the designer to instantly convert the general TRIZ method to their specific solution of the design feature. The use of morphological chart helps the designers to imagine
clearer idea to achieve the conceptual designs of the product [35].

3.6 Developing of creep testing rig with bracing system conceptual designs based on the combination identified systems elements

The conceptual design was selected based on the TRIZ initiative principles and morphological chart result, which focused on five designs, as shown in Fig. 5. These 3D CAD models were visualised in the actual dimensions to recognise the specification of the product design. The overall proposed design concepts are summarised as below based on Fig. 4:

1 For the material used, the mild steel was chosen due to its outstanding weldability and good finishing after the fabrication process. Furthermore, it has high strength and durability to have a good uniform and hard shell for a tall structure. In the previous finding, mild steel has better machinability and higher Brinell hardness than other forms of steel because it is produced from the hot-rolled steel [31,54].

2 The experimental setup implemented in the creep testing for actual size of cross arms was cantilever beam mode. In this case, the experiment is designed with the same mode condition used in lifting cable for cross arm in transmission tower.

<table>
<thead>
<tr>
<th>TRIZ solution principle and strategy</th>
<th>Design features</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of material</td>
<td>Mild steel</td>
<td>Gray cast iron</td>
</tr>
<tr>
<td>Structure condition</td>
<td>Cantilever beam</td>
<td>Three point bending</td>
</tr>
<tr>
<td>Type of connection for cross arm mounting</td>
<td>Fixed end</td>
<td>Pinned end</td>
</tr>
<tr>
<td>Degree of flexibility is identified by incorporate several locations of fastener on the creep testing rig</td>
<td>Measuring tool</td>
<td>Linear variable differential transformer (LVDT)</td>
</tr>
<tr>
<td>Lifting height</td>
<td>High</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Fig. 3 – Standard of small scale cantilever beam creep testing rig setup [53].

3 The cross arm structure was connected to the testing rig using fastener in form of pinned end. This connection was chosen due to easy to assemble and dissemble to change the cross arm with other types and sizes. The maintenance cost of the tested cross arm is lesser as compared to fixed end and very beneficial for joining dissimilar material of cross arm and testing rig [55,56].

Fig. 4 – Morphological chart of TRIZ solution principle and their design of creep testing rig design feature.
4 Axis support type of the proposed concept design of testing rig was horizontal. This was due to the applied load is given horizontally to test the durability of the cross arm.
5 The dial gauge with magnetic holder was used as the strain measuring tool in the morphological chart. This is due to its movability in measuring the strain of the specimen.
6 The loads exerted by a full-scale cross arm were simulated on the mounting area of the designed test rigs, which is at an elevated height from the ground. Since the height of cross arm is roughly 2–3 m, the testing rig should be designed to have a height of roughly 4 m to replicate actual condition in smaller scale [49,57].

3.7. Performing the design selection process using Analytic Network Process method using pairwise comparison technique based on product design specification (PDS)

In the selection design process, the ANP was implemented to assist in providing a systematic and overall multi-criteria decision-making process using the pairwise comparison technique [40]. The ANP is a concept that implements the generalisation of analytical hierarchy process (AHP) in dealing with the dependence and response in the decision-making process [34]. The ANP was used to select the best design concept to fulfil the product design specification (PDS) to develop a new creep testing rig for the full-scale cross arm. The project utilised the ANP method to finalise and select the best design concept among the five conceptual designs developed earlier.

The selection process was done according to the PDS for the new creep testing rig for the full-scale size cross arm, as displayed in Fig. 6.

PDS is one of the approaches used to compile the related standards and design goals in developing a product. In this case, the design specification of the creep test rig is required to follow a standard guideline of a cantilever beam structure to ensure the essential operation of the design is fulfilled. To be specific, the upgrade of the existing design conducted by a designer should follow the design strategy requirements. In this study, the designer outlined the product design specification, as shown in Fig. 6. Later, the PDS and design strategy requirement were tabulated using the ANP.

In Table 4, the performance evaluation of strength and deformation was used to determine the durability and reliability of the creep testing rig designs. Meanwhile, the weight criteria was set based on the density of the testing rig. The cost

<table>
<thead>
<tr>
<th>PDS main element</th>
<th>PDS-sub element</th>
<th>Equivalent design indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>Strength</td>
<td>Von Mises Stress (N/m²)</td>
</tr>
<tr>
<td>Weight</td>
<td>Stiffness</td>
<td>Deformation (mm)</td>
</tr>
<tr>
<td>Cost</td>
<td>Density</td>
<td>Volume (m³)</td>
</tr>
<tr>
<td></td>
<td>Raw material cost</td>
<td>Price (RM)</td>
</tr>
<tr>
<td></td>
<td>Manufacturing cost</td>
<td>Shape complexity</td>
</tr>
</tbody>
</table>

Fig. 5 – Proposed conceptual design of creep testing rig.

Table 4 – A summary of design strategy and PDS element and their equivalent design indicators for creep testing rig for full-scale cross arm.
attribute was also divided into raw material cost and manufacturing cost. The raw material cost and manufacturing cost were estimated from the weight obtained and the shape complexity of the structure design, respectively. Fig. 7 shows the square pipe sheet shape was used in order to develop the testing rig members.

The design strategy and PDS elements were compiled, and the selected design was done using the ANP selection process. In the ANP programme, the elements were arranged as in Fig. 8 to its hierarchy order.

Based on the ANP concurrent engineering technique, the selection of design concepts was done by using the pairwise comparison approach. Each of the alternative (design concepts) was given a numerical score to rank based on the relative comparison given in Table 5. At the beginning, every conceptual design was produced inside a 3D CAD modelling software to examine their features using the attributes that were set in the first place. A computational simulation was also carried out using the finite element analysis software to evaluate the structural performance of each model. In this process, the evaluation was made to characterise the deformation effect on each of the proposed product models based on the applied force. The mass value and shape complexity were identified based on each of the created CAD models to estimate the prices of the raw material and manufacturing cost for each of the conceptual design. To have better understanding, the evaluation of each design concept for the full-scale cross arm is shown in Fig. 9. In the end, four levels of ANP hierarchy were made to estimate the scores and ranking of these proposed designs depending on the main criteria and sub-criteria were set earlier as shown in Fig. 8.

The pairwise comparison of each design was assigned to select the best model among the main criteria and sub-criteria set in the PDS. A computational software, Super Decision 2.1 was used to execute the comparison results from the relationship between the four levels of ANP hierarchy, which are design goals, main criteria, sub-criteria, and alternatives. The evaluation process was done between all the concept designs with respect to each main criteria and sub-criteria selection. Fig. 10 shows the example of the pairwise judgment process between the concept designs concerning the weight criteria and cost criteria. The results were evaluated according to the performance of the creep testing rig, followed by cost and weight criteria in the design selection process. For the creep testing rig, the performance criteria are the vital element because the component must adapt high loading capacity from the cross arm.

According to the main goal set for design concepts development, Design Concept 5 exhibits the highest score among the concept designs, especially in terms of strength in the performance criteria. Based on the overall sensitivity result as displayed in Table 6, Concept Design 5 ranked the highest in all three simulated ratios. This is contributed to the use of numerical values in most of the pairwise comparison situation during the analysis. The results are consistent with the ANP result and validated the reported outcome of the selection process.

At the end of selection process, Concept Design 5 has the highest score among the concept designs. This is due to the applied bracing system pattern. Fig. 11(a) shows that Concept Design 5 has the highest performance and weight attribute. This is because, the incorporation of hybrid bracing between V-bracing, cross bracing, and single diagonal allows the lowest Von Mises stress on the product. This shows that the hybridisation of several bracing systems and the arrangement of bracing in a product allows the product to withstand the applied load from the cross arm and dead weight, and the intended bracing system provides better tensile force resistance and yielding from the external loads. Furthermore,
Table 5 – Summary of creep testing rig for full-scale cross arm concept design overall attributes.

<table>
<thead>
<tr>
<th>Design selection attributes</th>
<th>Concept designs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>1</td>
</tr>
<tr>
<td>Max. stress (Von-Mises stress, (N/m²))</td>
<td>72.376</td>
</tr>
<tr>
<td>Max. deformation (mm)</td>
<td>4.334</td>
</tr>
<tr>
<td>Weight</td>
<td>4302.4</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>0.548</td>
</tr>
<tr>
<td>Cost</td>
<td>6,453.60</td>
</tr>
<tr>
<td>Raw material cost (RM)</td>
<td>Low</td>
</tr>
<tr>
<td>Shape complexity</td>
<td></td>
</tr>
</tbody>
</table>

Note: For comparison purposes, assumed creep testing rig for full-scale cross arm density is 7850 kg/m³, and the raw cost of material is RM 1.50 per kg.

Table 6 – Overall synthesized for the alternatives.

<table>
<thead>
<tr>
<th>Design</th>
<th>Normal</th>
<th>Ideal</th>
<th>Graphic bar</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.185016</td>
<td>0.550312</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>0.118163</td>
<td>0.351465</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>0.127633</td>
<td>0.379633</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>0.232986</td>
<td>0.692995</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>0.336202</td>
<td>1.000000</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

the predicted deformation behaviour in the FEA shows the lowest deformation value with only 0.176 mm. Apart from that, Concept Design 5 has relatively similar raw material cost and shape complexity with the other three concept designs (except Concept Design 1) which caused the comparison to be insignificant. Lastly, Fig. 11(c) shows that the weight of testing rig structure should be higher to provide better stability and structural integrity when the multi-directional forces were installed on the cross arm when the test was conducted. This statement is also supported in Table 5, which explains that Concept Design 5 has the highest weight among the others.
<table>
<thead>
<tr>
<th>Design</th>
<th>Weightage evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept design 1</td>
<td><img src="image1" alt="Conceptual design evaluation data" /></td>
</tr>
<tr>
<td>Concept design 2</td>
<td><img src="image2" alt="Conceptual design evaluation data" /></td>
</tr>
<tr>
<td>Concept design 3</td>
<td><img src="image3" alt="Conceptual design evaluation data" /></td>
</tr>
<tr>
<td>Concept design 4</td>
<td><img src="image4" alt="Conceptual design evaluation data" /></td>
</tr>
<tr>
<td>Concept design 5</td>
<td><img src="image5" alt="Conceptual design evaluation data" /></td>
</tr>
</tbody>
</table>

**Fig. 9** – Conceptual design evaluation data.

**Fig. 10** – The ANP using pairwise comparison in design selection process.
4. Conclusion

As a conclusion, a new conceptual design for creep testing rig was established using the TRIZ-morphological chart-ANP method in this project. The design concepts were possible to be developed due to the implementation of TRIZ 40 inventive principles method, which are #6 universality, #35 parameter changes, and #1 segmentation. These solution principles were generated to visualise several conceptual designs and further refined using the morphological chart. The overall synthesised alternative analysis shows Concept Design 5 scored and ranked first. Concept Design 5 was chosen as the final design concept because it exhibits the highest priority value compared to other four alternatives in all three simulated scenarios. Based on the integration of TRIZ-morphological chart-ANP into one single hybrid solution method contributes in term of ability to practised hand-in-hand. This method is a comprehensive concurrent engineering method to achieve a systematic process to generate ideas, refine ideas, develop design approach, and select the best design concept for the creep testing rig. In future, it is recommended to conduct further comprehensive study on the finite element analysis to analyse the structural behaviour of the final design for the creep testing rig of full-scale cross arm.

Conflicts of interest

The authors declare no conflict of interest.

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