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# Optimizing product design and development of engine carbon cleaning maintenance tools using reverse engineering and VDI 2222 methods

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**ABSTRACT**
This research article explains the product design and development optimization of multi feature engine carbon cleaning maintenance tools. The implementation of the Reverse Engineering method was integrated with VDI 2222 in the research process. The results of the optimal design and development of this tool obtained a component structure that was able to meet 14 types of consumer needs with a total tools cost of IDR 1.137.900 with a total tool weight of 6.9 kg. The results of the load test simulation concluded that the housing case was able to withstand the overall weight of the components that make up the tool. Depending on the liquid chemical used, the results of tool tests on a limited scale have proven to be able in save fuel consumption by ±12.5% per hour with engine workload which can also be reduced by 3.14%.

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## 1. INTRODUCTION

The growth of vehicle users in Indonesia is very high in line with the country's economic growth. In line with this, it means that the level of financial capability of the community is also increasing so that it can also increase the purchasing ability of a product, especially in the secondary and tertiary goods category, or in this case are vehicles. The rapid economic growth of Indonesia is also due to the factor of equal distribution of economic development to each region, this is because the economy is not centralized so that the wider community is able to participate in developing the economic progress of their region and increasing prosperity [1]. This of course makes people's mobility increase because every region, both within cities, between cities and provinces, will use various types of vehicle transportation as a means of mobility for various purposes. Therefore, vehicles have a vital role in carrying out community activities, especially in relation to the development of the nation's economy, so they need to be of concern to all groups. However, the large number of people owning and using vehicles can of course have both positive and negative impacts. The negative impact of this is that it has the potential to increase the number of carbon emissions resulting from the operation of vehicles, so that governments in various countries have even implemented carbon emission threshold regulations as a form of attention and efforts to save the environment due to the impact of carbon release into the environment which is one of the factors the cause of global warming and the poor quality of air pollution which of course can cause further potential, namely in terms of public health [2-3]. However, the high number of vehicle users can also have a positive impact, including the development of automotive industry technology, vehicle accessories, fuel filling stations and even workshops for various types of vehicle maintenance spread across various regions which of course are able to provide a lot of benefits, such as employment opportunities to improve the community's economy.

According to the Indonesia Ministry of Energy and Mineral Resources, the population of vehicles, especially two-wheeled vehicles, is more than 120 million units with an annual growth rate of 5% to 6%, where the equivalent in terms of fuel use of 1 liter per day produces 2.5 kg of emissions (use of fuel and the process of making the fuel) or as many as 300 million kg of total emissions from the entire population of two-wheeled vehicles in Indonesia [4]. Through the percentage growth rate for two-wheeled vehicles, it is predicted that in 2024 it will reach 150 million units, which of course means that the total emission value will increase further and this number does not include other types of vehicles, namely four-wheeled vehicles and commercial vehicles such as trucks, buses and so on. Vehicles that do not meet emission limit regulations are indicated due to minimal maintenance of the motorized vehicle's engine. Through the Ministry of the Environment, regulations regarding motorized vehicle emission thresholds have been determined using EURO IV standards [2-3]. The vehicle maintenance process, especially to overcome high emissions rates, can be carried out in workshops according to the type of vehicle used.

The issues that arise in terms of vehicle maintenance known as engine carbon cleaning maintenance, is in fact not cheap. First that engine carbon cleaning tools on the market are sold separately according to the type of carbon cleaning on engine components (injector cleaner tools, combustion chamber cleaner tools and catalytic converter cleaner tools) which are not cheap for investments and on average only vehicle workshops have these devices. Second engine carbon cleaning maintenance service fees are also not cheap, this is what makes the cost of engine carbon cleaning services quite expensive, so it is not uncommon for vehicle users to only carry out regularly or periodically maintenance on the engine but ignore maintenance for cleaning carbon on their vehicle's engine and the issues resulting in high emission rates from vehicles. The needs for this condition are how to provide vehicle maintenance tools for engine carbon cleaning with affordable equipment prices but can effectively reduce emissions and be efficient in the operational costs of using the tools so that the cost of engine carbon cleaning maintenance can be cheap, resulting in reduce of emission rates from vehicles according to established emission vehicle standards. The problems is how to design and development an engine carbon cleaning maintenance tools that has multiple features (injector cleaner, combustion chamber cleaner and catalytic converter cleaner) on one tool by considering economic aspects and quality of results. The purposes are to design and development a multi-feature engine carbon cleaning maintenance tools based on optimizing economic and quality parameters using the Reverse Engineering and VDI 2222 (Verein Deutcher Ingenieure) methods. The use of the VDI 2222 method is complementary in terms of optimization of the design process using the Reverse Engineering method. Several types of VDI methods include VDI 2225, VDI 2223, VDI 2222 and VDI 2221, selecting the VDI 2222 method involves process planning, analysis and execution of product design, from ideation to become a prototype, this is because this method is a systematic approach to the concept variations in development and design of technical systems and products so that it is suitable for optimizing design results from the Reverse Engineering method. Previous, current and future scientific literature related to engine carbon cleaning which is a reference for researchers is summarized in Table 1.

**Table 1.** Scientific Literacy

| Research Map | Years | Review |
|---|---|---|
| Past | 2014 | Effect of using different liquid fuels on combustion chamber cleaning [5] |
| | 2018 | Effectiveness of high carbon alcohols as oxygenation additives for cleaner emissions [5],<br>three-way honeycomb catalytic converters on their effect and service life for reducing emissions [6] |
| | 2019 | Impact of ceramic coating on engine performance and emission characteristics for clean production [7] |
| | 2020 | Diesel engines and diesel-gasoline fuel mixtures with a low temperature combustion process in the engine to obtain clean combustion [8],<br>Catalytic converters which were studied in CI engines for their performance in reducing emissions [9] |
| | 2021 | Impact of a mixture of diesel and gasoline on engine cylinders to achieve clean combustion efficiency [10], |

| Research Map | Years | Review |
|---|---|---|
| | | Emission characteristics of compression engines with silver and zinc coatings on catalytic converters [11],<br>Catalytic converters in the exhaust of two-wheeled motorized vehicles in terms of their performance in reducing emissions [12],<br>Application of diagnostic techniques in the combustion chamber maintenance process of 812 series diesel engines [13] |
| | 2022 | Effectiveness of reducing emissions through a catalytic converter and oxygen sensor replacement program [14],<br>Extraction efficiency of critical catalytic elements in vehicle converters using alkaline treatment with cleaning agents [15] |
| | 2023 | Combustion and emission characteristics of a mixture of ABE fuel and gasoline for CISI engines [16],<br>Effectiveness of combustion and exhaust cleanliness with water and cetane improver [17],<br>Efficiency and clean combustion using ICCI engines at low load conditions [18],<br>Controlling hydrocarbon emissions using adsorptive catalytic gasoline particulate filters for gasoline engines [19],<br>Three-way catalytic converters in the combustion process and emission characteristics for gasoline engines [20],<br>Acetone material for cleaning the combustion chamber in diesel engines [21],<br>Mixing octanol with biodiesel for efficiency and cleaning the combustion chamber in diesel engines [22],<br>Flow field uniformity and temperature fields in gasoline engine catalytic converters [23],<br>Three-way catalytic converters for two-wheeled vehicles [24],<br>Improving the catalytic performance of the converter to reduce emissions with thermal storage [25],<br>Emission analysis in catalytic converters using nano material coatings [26] |
| Present | 2024 | Artificial neural network models for forecasting combustion characteristics and emissions from ethanol-gasoline DFSI engines [27],<br>Optimizing catalytic reduction in diesel engines with urea injection [28],<br>Impact of hydrogen peroxide in the combustion process and emissions using ethanol-gasoline [29],<br>Impact of hydrogen injection regarding combustion stability in gasoline engines [30],<br>Use of oxyhydrogen to improve the combustion process and emission characteristics from the use of isopropanol-gasoline for injection engines [31],<br>Influence of fuel and air supply to the combustion chamber in relation to reducing the content of dangerous emission substances [32],<br>Combustion and emission optimization in natural gas-powered diesel engines [33],<br>Determine the risk factors for carbon monoxide toxicity in catalytic converters [34] |
| Future | | Through scientific reference literacy studies that have been carried out, there are many recommendations for further research in the research development process, including:<br>Optimization and development of technology for gasoline-diesel engine carbon cleaning devices, optimization and development of engine carbon cleaning fluid, coating technology in the engine carbon cleaning process, development of methods and technical processes for engine carbon cleaning, implementation variations of optimization methods along with advanced parameters and factors, etc |

## 2. MATERIALS AND METHODS

This research focuses on designing multi-feature engine carbon cleaning maintenance tools based on consumer needs. The technical design of the tools applies the Reverse Engineering method for the design and development process and also VDI 2222 (Verein Deutcher Ingenieure) for the design optimizing and protoyping.

### *2.1. Research Flow Process*

This research flow process is shown in Figure 1.

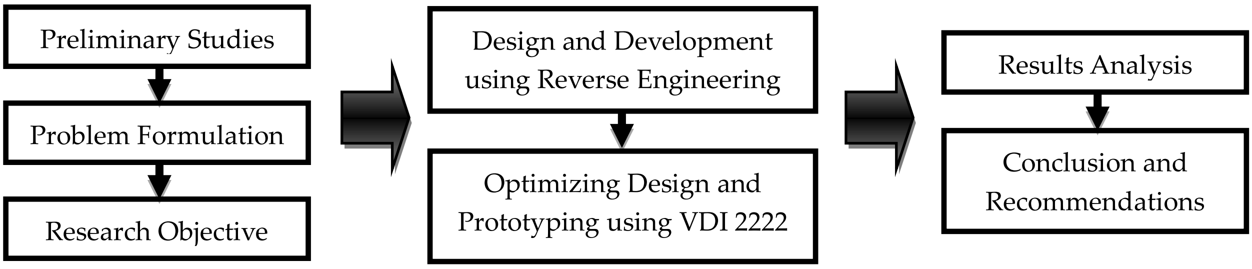



**Figure 1.** Research Flow Process

a. **Preliminary Studies**. This is the first stage of research which aims to identify issues and needs, then supported by literature studies, field observations and interviews to strengthen the facts in the technical problem formulation.
b. **Problem Formulation**. The second stage of this research is formulating the problem. The problems in this research is how to design and development an engine carbon cleaning maintenance tools that has multiple features (injector cleaner, combustion chamber cleaner and catalytic converter cleaner) on one tool by considering economic aspects and quality of results.
c. **Research Objective.** The third stage of this research is determining the objectives. The purposes in this research is to design and development a multi-feature engine carbon cleaning maintenance tools based on optimizing economic and quality parameters using the Reverse Engineering and VDI 2222 methods.
d. **Design and Development**. The fourth stage of this research is the design and development of engine carbon cleaning maintenance tools, where the technical design process applies the Reverse Engineering method. The stages of this method are (i) Disassembly, (ii) Assembly, (iii) Target specifications and (iv) Product design and Development.
   The Reverse Engineering method itself can be applied to the analysis of deformation factors in relation to complex metal welding processes [35]. This method is also described as being able to describe the surface reconstruction of a product [36]. Apart from that, it can also be developed how this method is directed towards sustainable aspects [37]. In further research, this method was able to integrate 3D scan technology [38]. This method has also been proven capable of engineering reconstructed gear products via point clouds [39]. Furthermore, this method is also capable of displaying physical virtual models [40] and this method can even be combined with multi-criteria decision making in the remanufacturing process [41].
e. **Optimizing Design and Prototyping**. The fifth stage of this research is optimizing the design and making prototypes of engine carbon cleaning maintenance tools, where the technical aspects of this stage apply the VDI 2222 (Verein Deutcher Ingenieure) method. The stages of this method are (i) Planning and design development concepts, (ii) Technical calculation and (iii) Prototyping.
   This method has been used in innovative concept machine development by specifically applying variations of the VDI 2221 method [42]. The VDI 2221 method has also been proven capable of being applied to the development of additive manufacturing combination machining processes [43]. Meanwhile, the VDI 2222 method itself can be applied in the development of engine products using environmentally friendly renewable energy sources [44].

f. **Results Analysis**. The sixth stage of this research is conducting an analytical study of the design, realization of the physical prototype and performance of the tool.
g. **Conclusion and Recommendations**. The final stage of this research is to summarize the conclusions and provide recommendations regarding tool development and suggestions for further research.

*2.2. Data Collection*

a. **Observation**. Data from field observations are in the form of technical data related to similar tools, components that make up the tools and research supporting raw materials available on the market (type, price, dimensions, use and installation).
b. **Interview**. The data from the interviews is in the form of data on consumer needs regarding engine carbon cleaning maintenance tools. The selected respondents were four-wheeled vehicle repair mechanics and several experts in the field of vehicle engines.
c. **Literature study**. Data from the results of the literature study are technical data from previous research related to tools, technical standards for the components that make up the tools, technical standards for testing and stages of the Reverse Engineering and VDI 2222 methods.

## 3. RESULTS

This section explains how to implement the Reverse Engineering and VDI 2222 (Verein Deutcher Ingenieure) methods in the technical design process of engine carbon cleaning maintenance tools.

3.1. Reverse Engineering

A market survey is needed first to identify devices that are generally available on the market regarding engine carbon cleaning maintenance tools (injector cleaning tools, combustion cleaning tools and catalytic cleaning tools). The results of the market survey show that this equipment is sold separately for each cleaning function under various brands. The market survey results regarding these products are shown in Table 2.

**Table 2.** Market Products of Engine Carbon Cleaning Maintenance Tools

| No | Tools | Merk | Product Illustration |
|---|---|---|---|
| 1 | Injector cleaning tools (infuse aerosol can system) | Autofit, SR15, GST52, Jireh, Ergene, etc |  |
| 2 | Injector cleaning tools (infuse air regulator system) | Autofit, Wurth, Ergene, JP, etc |  |

Table 2. Market Products of Engine Carbon Cleaning Maintenance Tools (continued)

| No | Tools | Merk | Product Illustration |
|---|---|---|---|
| 3 | Combustion chamber cleaning tools | Autofit, Grip on, Ergenlube, etc |  |
| 4 | Catalytic cleaning tools | Liqui molly, No brand, etc |  |

a. Disasembly

This stage is the dismantling activity of the device in Tabel 2 with the aim of finding out more about all the components of the device with all the technical specifications it has. The results of these activities are shown in Table 3.

Table 3. Product Dissasembly

| No. | Tools | Components | Materials | Size | Qty (Pcs) |
|---|---|---|---|---|---|
| 1 | Injector cleaning tools (infused aerosol can system)<br><br>Average of Length: 14 cm Width: 4 cm Height: 17,5 cm (without flexible hose) Weight: 1 kg Approx. market price: IDR 800,000 | Can tap valve | Brass | Inlet thread 5/6 inch type R410/R32, outlet rough thread 1/4 inch type R22 | 1 |
| | | Control valve | Stainless steel | 1/4 inch, ball type stop valve | 1 |
| | | Pressure gauge | Standard EN 837-1 | Max measuring pressure 6 bar | 1 |
| | | Swivel | Brass or stainless steel | Inner rough thread 1/4 inch, outer thread 1/4 inch | 1 |
| | | Tee fitting | Brass | 1/4 inch, outer thread | 1 |
| | | Flexible hose | Standard SAE 30 for fuel and oil hose | 5/16 inch, inlet dia. 8 mm, length 1.5 m – 2 m | 1 |
| | | Fuel coupler/ connector | Standard fuel connector nipple | Straight type, 6 mm coupler | 1 |
| | | Hose clamp | Stainless steel | 3/4 inch | 2 |
| | | Hose nipple | Brass or stainless steel | 1/4 inch male outer thread, nipple hose 1/4 inch – 3/8 inch | 1 |

**Table 3.** Product Disasembly (continued)

| No. | Tools | Components | Materials | Size | Qty (Pcs) |
|---|---|---|---|---|---|
| 2 | Injector cleaning tools (infused air regulator system)<br><br>Average of Length: 14 cm Width: 8 cm Height: 24 cm (without flexible hose) Weight: 2 kg Approx. market price: IDR 1,000,000 | Fluid tube | Stainless steel | 250 ml – 500 ml | 1 |
| | | Control valve | Stainless steel | 1/4 inch, ball type stop valve | 1 |
| | | Regulator pressure | Standar air regulator | 1/4 inch | 1 |
| | | Pressure gauge | Standard EN 837-1 | Max measuring pressure 6 bar | 1 |
| | | Flexible hose | Standard SAE 30 for fuel and oil hose | 5/16 inch, inlet dia. 8 mm, length 1.5 m – 2 m | 1 |
| | | Fuel connector coupler nipple | Standard fuel connector nipple | L type, 6 mm coupler | 1 |
| | | Quick release male coupler | Stainless steel | 1/4 inch, PM 20 type | 1 |
| | | Hose clamp | Stainless steel | 3/4 inch | 2 |
| | | Hose nipple | Brass or stainless steel | 1/4 inch male outer thread, nipple hose 1/4 inch – 3/8 inch | 1 |
| 3 | Combustion chamber cleaning tools<br><br>Average of Length: 13,5 cm Width: 7 cm Height: 26,5 cm (without flexible hose) Weight: 2 kg Approx. market price: IDR 1,000,000 | Vacuum tube | Stainless steel or HDPE | 1 lt – 1.5 lt | 1 |
| | | Pneumatic vacuum ejector valve | Standard pneumatic alumunium component | 1/8 inch | 1 |
| | | Pneumatic silencer | Brass | Outer thread 1/8 inch or 10 mm, type BSL | 1 |
| | | Control valve | Brass | Inlet thread 1/4 inch, outlet thread 1/8 inch | 1 |
| | | Quick release male coupler | Stainless steel | 1/4 inch, PM 20 type | 1 |
| | | Flexible hose | PU | Outer dia. 8 mm, inner dia. 5 mm, length 1.5 m | 1 |
| | | Double nipple | Brass | thread 1/8 inch | 2 |
| | | Hose nipple | Stainless steel | Hose dia. 5 mm, outer male thread 1/8 inch | 1 |
| 4 | Catalytic cleaning tools<br><br>Average of Length: 5 cm Width: 4,5 cm Height: 24 cm (without flexible hose) Weight: 0,5 kg Approx. market price: IDR 600,000 | Cap tube | Stainless steel | 1 inch | 1 |
| | | Control valve | stainless steel | 1/4 inch, ball type stop valve | 1 |
| | | Flexible hose | PU | Outer dia. 8 mm, inner dia. 5 mm, length 1.5 m – 2 m | 1 |
| | | Tube hose | PU or alumunium pipe | Outer dia. 12 mm, inner dia. 8 mm, length 15 cm | 1 |
| | | Pneumatic silencer | Brass | Outer thread 1/8 inch or 10 mm, type BSL | 1 |
| | | Pneumatic hose female slip lock | Brass | Hose 12 mm, outer thread 1/4 inch, MPCF 12-02 type | 1 |
| | | Pneumatic hose female slip lock | Brass | Hose 8 mm, inner thread 1/4 inch, MPCF 08-02 type | 1 |
| | | Hose nipple | Brass | 1/4 inch male outer thread, nipple hose 5/16 inch | 1 |
| | | Pneumatic elbow control speedslip lock | Standard pneumatic component | Hose 8 mm, outer thread 1/4 inch, MSL type | 1 |
| | | Hose clamp | Stainless steel | 3/4 inch | 1 |

b. Assembly

This stage is a reassembly activity of a device that has been disassembled and all components and previous technical specifications identified. The purpose of this reassembly process is to find out how the technical assembly of all the components that make up the tool is carried out in order to be able to create a technical assembly mapping. Figure 2 is a technical assembly chart of the market product of engine carbon cleaning maintenance tools.

c. Target Specifications

At this stage, consumer needs are first identified through a field observation process to find out the voice of customer towards several expert mechanics and vehicle engineering experts regarding the ideal multi feature engine carbon cleaning maintenance tools desired. The results of identifying these needs were obtained from interviews with several respondents who were four-wheeled vehicle repair mechanics and several experts in the field of vehicle engines. As for the results, were obtained 14 types of consumer needs. Furthermore, determine the achievement target specifications by mapping technical responses in order to design ideal multi feature engine carbon cleaning maintenance tools to meet consumer needs. The results of the technical response mapping are shown in Table 4.

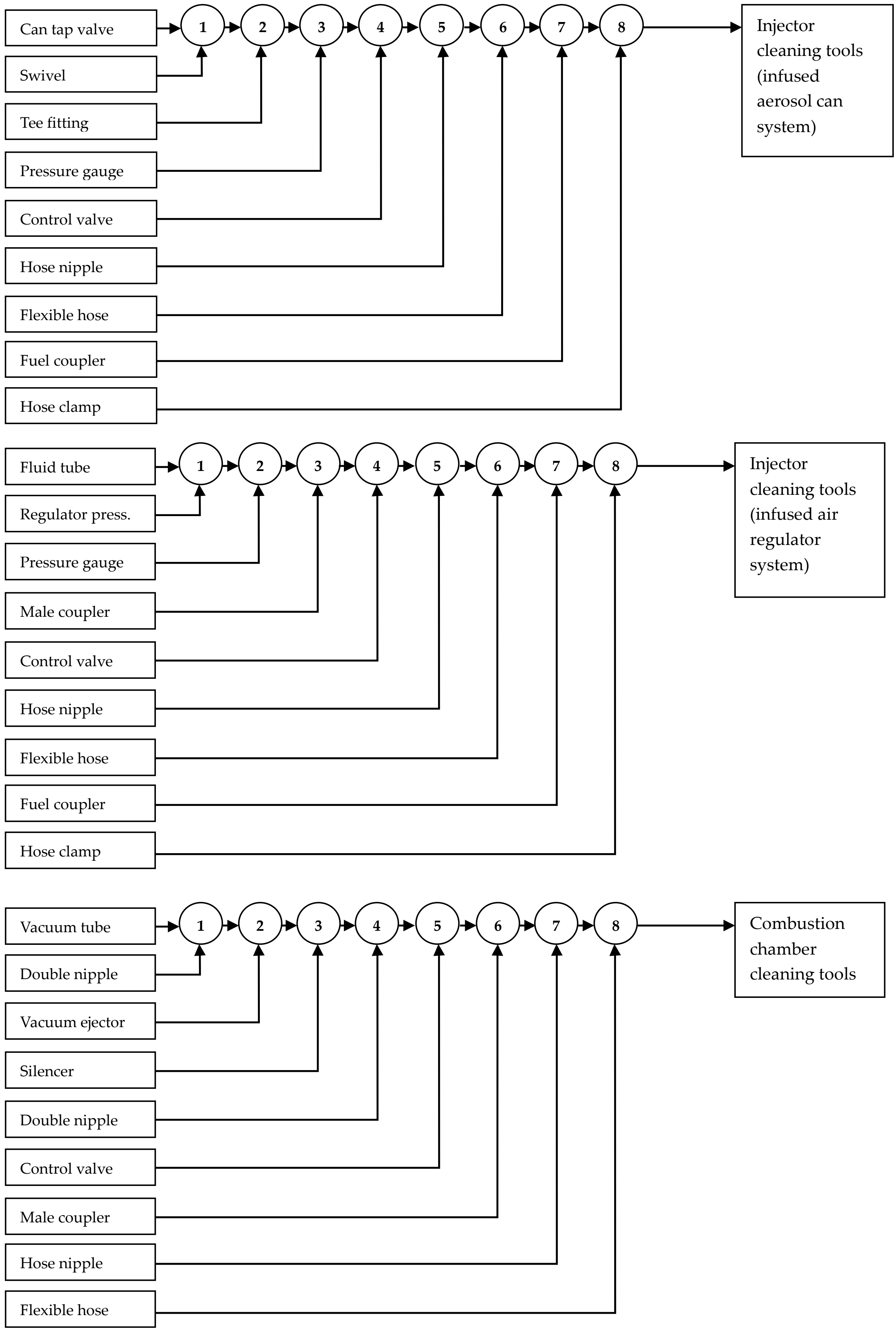
**Table 4.** Mapping Technical Responses of Tools Specification

| No. | Consumer Needs | Technical Response |
|---|---|---|
| 1 | Multi feature on 1 tool | Using VDI 2222 (Verein Deutcher Ingenieure) methods for optimizing design |
| 2 | Easy to use | |
| 3 | Durable design | |
| 4 | Easy to move | Using reliable stand holder as a part of components |
| 5 | Easy to adjust in height | |
| 6 | No need holding with hand | |
| 7 | Economical pricing | Using standard and commonly used components |
| 8 | Durable material | |
| 9 | Low maintenance costs | |
| 10 | Anti rust | |
| 11 | Easy to clean | Using open housing box design for components bracket |
| 12 | Easy to maintenance | |
| 13 | Effective to use | Using market product proof mechanism design with improved modification |
| 14 | Safe to use | |

After mapping the technical responses then determine the target specification for design and development process. Table 5 shows the target design specifications.

d. Product Design and Development

Based on the evaluation results in the previous stage, at this stage the design realization is made so that it can create multi-feature engine carbon cleaning maintenance tools. The design process for the tool design refers to the results of Reverse Engineering from products available on the market (see Table 3 for disassembly and Figure 2 for assembly chart), then developed according to the target specifications in Table 5, If we observe from the target specification table the customer of voice leads to the previous Table 4 where consumers expect a practical machine carbon cleaning tool (in the sense that it is available in 1 tool). This is a strong justify for designing multi-feature carbon tool engines as shown in Figure 3 that shows the product design in 3D rendering visualization if a physical prototype will be made.


Can tap valve
Swivel
Tee fitting
Pressure gauge
Control valve
Hose nipple
Flexible hose
Fuel coupler
Hose clamp
1
2
3
4
5
6
7
8
Injector cleaning tools (infused aerosol can system)
Fluid tube
Regulator press.
Pressure gauge
Male coupler
Control valve
Hose nipple
Flexible hose
Fuel coupler
Hose clamp
1
2
3
4
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6
7
8
Injector cleaning tools (infused air regulator system)
Vacuum tube
Double nipple
Vacuum ejector
Silencer
Double nipple
Control valve
Male coupler
Hose nipple
Flexible hose
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Combustion chamber cleaning tools

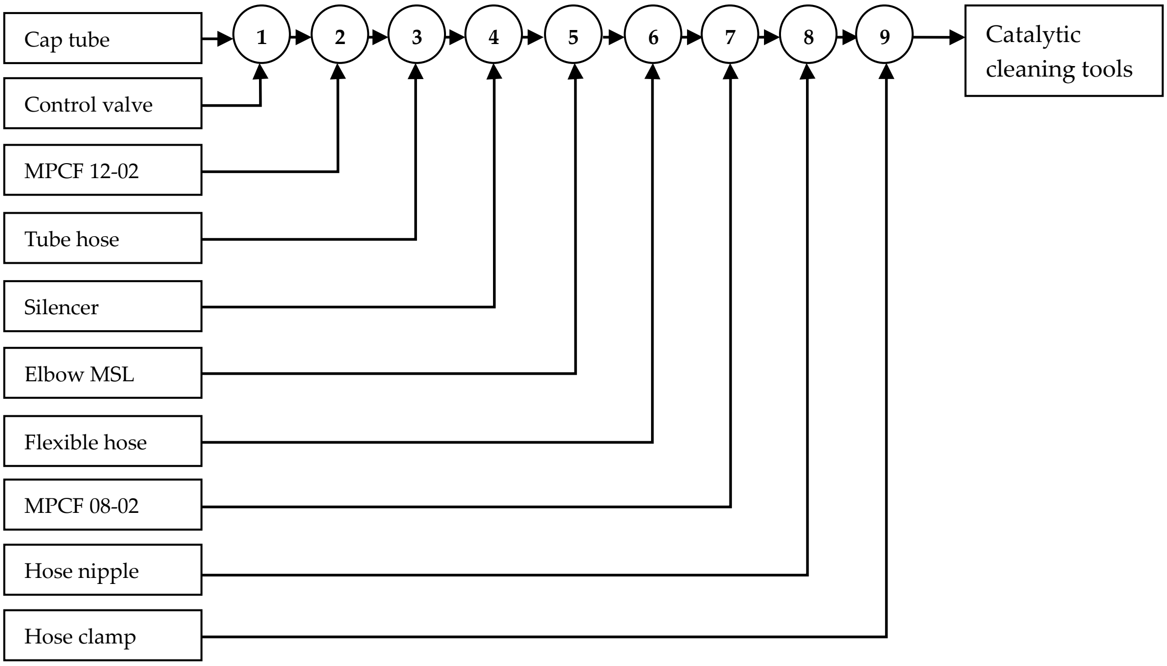



**Figure 2.** Market Product of Engine Carbon Cleaning Maintenance Tools Assembly Chart

3.2 VDI 2222 (Verein Deutcher Ingenieure)

*a. Planning and Optimizing Design Concepts*

Using the VDI 2222 method in the process of planning and optimizing design concepts, optimal design variation concepts (VC) can be obtained for each system structure with target specification parameters that have been previously obtained through the Reverse Engineering method and further analysis regarding component costs (IDR) and weight of the components. (gr). Table 6 shows the planning design concept for multi feature engine carbon cleaning maintenance tools.

**Table 5.** Target Design Specifications

| Technical Response | Target Specifications |
|---|---|
| Using VDI 2222 (Verein Deutcher Ingenieure) methods for optimizing design | **1.** Switching design in injector cleaner feature using standard 3 way valve for infuse aerosol can system and air regulator system<br>**2.** Switching design in air compressor supply using standard 3 way valve for injector cleaner tool using infuse air regulator supply and for combustion chamber cleaner tool |
| Using market product proof mechanism design with improved modification | **3.** Air supply filter design using double air filter regulator with size ¼ inch (inlet – outlet) for air filtering (prevent rust, dust, water and oil from compressor tube)<br>**4.** Housing box design for installing all components using cubic type 25 cm x 25 cm x 25 cm for compact design (outside for main components and inside for connecting hose)<br>**5.** Operation monitoring design using oil and gas pressure gauge EN837-1 standard for safety process<br>**6.** Using check valve 1/4 inch (one way valve) in liquid tube inlet for safety purpose (no back pressure from the fluid)<br>**7.** Mechanism tool design will adopt market standard for safety purpose |
| Using reliable stand holder as a part of components | **8.** Stand holder for housing case support using tripod |
| Using standard and commonly used components | **9.** Piping, valve and tube components using anti corrosive materials from standard brass ASTM B687, standard stainless steel ASTM A182 or standard pneumatic components |

| Technical Response | Target Specifications |
|---|---|
| | **10.** Standard piping and valve size ¼ inch<br>**11.** Hose components using flexible hose for fuel or oil and anti corrosive materials from standard rubber nylon SAE 30<br>**12.** Standard hose size 5/16 inch<br>**13.** External air compressor using standard 1 hp oiless type with max 7 bar air pressure and standard spiral air hose |
| Using open housing box design for components bracket | **14.** Bracket case components using hard, bulky, clear and anti corrosive materials from acrylic, solid polycarbonate, stainless steel or galvanized plate<br>**15.** Thickness case material ≥ 3 mm<br>**16.** Case design with 1 side is opened for easy components maintenance, replacement and installing |

By tabulating planning design concepts in Table 6, related conclusions can then be drawn of optimizing design concept for multi feature engine carbon cleaning maintenance tools. The following is a mathematical model of the results of this optimal concept.

$$VC1 = AA1 + AB2 + AC2 + AD1 + AE2 + AF1 + AG1 + AH2 + AI1 \quad (1)$$

$$VC2 = BA3+BB1+BC2+BD1+BE2+BF1 \quad (2)$$

$$VC3 = CA1 + CB2 + CC2 + CD3 + CE1 + CF1 + CG3 + CH2 + CI1 \quad (3)$$

$$VC4 = EA3 + EB2 + EC3 + FA1 \text{ (excluded air compressor and leveling tripod)} \quad (4)$$

*b. Technical Calculation*

The technical calculation here will measure the manufacturing costs of multi-feature engine carbon cleaning maintenance tools based on an optimal design concept in the Total Cost (TC) parameter and the total weight of the tool in the Total Weight (TW) parameter. The results of these calculations are as follows.

$$\begin{aligned} TC\ VC1 &= C\ AA1 + C\ AB2 + C\ AC2 + C\ AD1 + C\ AE2 + C\ AF1 + C\ AG1 + C\ AH2 + C\ AI1 \\ &= 145{,}000 + 75{,}000 + 67{,}600 + 33{,}500 + 65{,}000 + 70{,}500 + 85{,}750 + 13{,}700 + 9{,}000 = 565{,}050 \end{aligned} \quad (5)$$

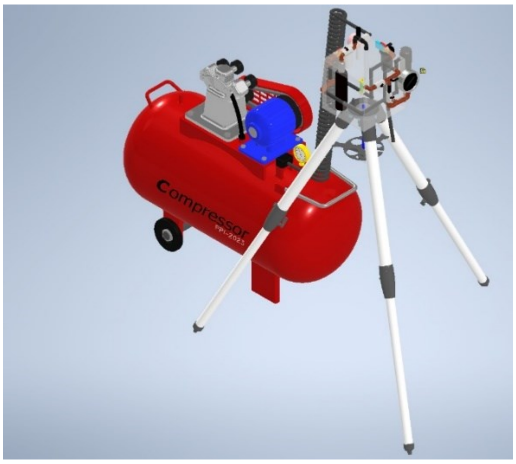
$$\begin{aligned} TC\ VC2 &= C\ BA3 + C\ BB1 + C\ BC2 + C\ BD1 + C\ BE2 + C\ BF1 \\ &= 69{,}000 + 93{,}300 + 19{,}000 + 27{,}500 + 7{,}600 + 3{,}000 = 219{,}400 \end{aligned} \quad (6)$$

$$\begin{aligned} TC\ VC3 &= C\ CA1 + C\ CB2 + C\ CC2 + C\ CD3 + C\ CE1 + C\ CF1 + CG3 + C\ CH2 + C\ CI1 \\ &= 17{,}000 + 23{,}000 + 34{,}100 + 3{,}500 + 23{,}350 + 10{,}000 + 8{,}400 + 7{,}600 + 1{,}500 = 128{,}450 \end{aligned} \quad (7)$$

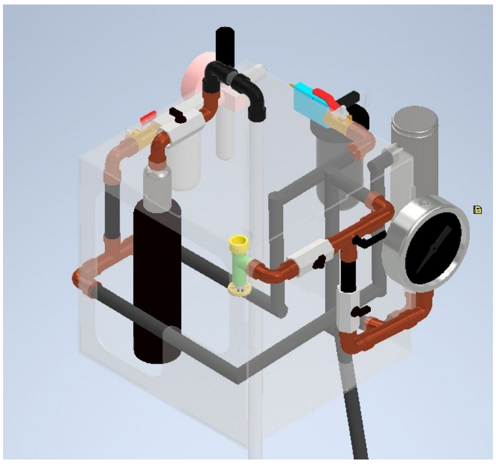
$$\begin{aligned} TC\ VC4 &= C\ EA3 + C\ EB2 + C\ EC3 + C\ FA1 \\ &= 70{,}000 + 65{,}000 + 20{,}000 + 70{,}000 = 225{,}000 \end{aligned} \quad (8)$$

$$\begin{aligned} TC &= TC\ VC1 + TC\ VC2 + TC\ VC3 + TC\ VC4 \\ &= 565{,}050 + 219{,}400 + 128{,}450 + 225{,}000 = IDR\ 1{,}137{,}900 \end{aligned} \quad (9)$$

(a)



(b)



(c)

**Figure 3.** 3D Render Design Visualization of Multi-Feature Engine Carbon Cleaning Maintenance Tools (a) Side View, (b) Overall Front View, (c) Detailed Component View

In calculating the total cost of the multi feature engine carbon cleaning device, the value was IDR 1,137,900 excluding the air compressor system components and leveling tripod. When compared with similar devices on the market which are sold separately (see Table 3) for injector cleaning tools (infused aerosol can system and air regulator system), combustion chamber cleaning tool and catalytic cleaning tool with a total of IDR 3,400,000, the prototype design results of multi feature engine carbon cleaning tool are obtained with a more economical cost of IDR 2,262,100.

**Table 6.** Planning Design Concepts

| **System Structure** | **Sub Component System** | **Node** | **Component Variations** | | | **Target Spec.** | **Add. Analysis** |
|---|---|---|---|---|---|---|---|
| | | | **1** | **2** | **3** | | |
| Injector cleaning system (VC1) | Fluid tube | AA | Stainless steel 250 ml | Stainless steel 500 ml | HDPE | 7, 9 | IDR 145,000 500 gr |
| | Can tap | AB | Can tap type 341 with no swivel | 341 with swivel | | 7, 9 | IDR 75,000 150 gr |
| | Piping and nipple | AC | Stainless steel | Brass | | 9, 10 | IDR 67,600 410 gr |
| | Pressure gauge | AD | EN 837-1 (6 bar measure) | EN 837-1 (10 bar measure) | | 5, 7, 13 | IDR 33,500 150 gr |
| | Switching valve | AE | Reguler ball valve with tee | 3 way valve | | 1, 7, 9, 10 | IDR 65,000 220 gr |

| System Structure | Sub Component System | Node | Component Variations 1 | 2 | 3 | Target Spec. | Add. Analysis |
|---|---|---|---|---|---|---|---|
| | | | fitting | | | | |
| | Control valve | AF | Stainless steel | Brass | | 7, 9, 10 | IDR 70,500 360 gr |
| | Flexible hose | AG | SAE 30 (standard oil and fuel) | PU (standard pneumatic) | | 7, 11, 12 | IDR 85,750 735 gr |
| | Fuel coupler | AH | Straight type | L type | | 7, 9 | IDR 13,700 300 gr |
| | Hose clamp | AI | Stainless steel thread clamp | Spring hose clamp | Cable ties | 7, 9 | IDR 9,000 90 gr |
| Combustion chamber cleaning system (VC2) | Vacuum tube | BA | Stainless steel 250 ml | Stainless steel 500 ml | HDPE | 7, 9 | IDR 69,000 650 gr |
| | Vacuum ejector valve | BB | Standard pneumatic | | | 7, 10 | IDR 93,300 150 gr |
| | Piping, nipple and silencer | BC | Stainless steel | Brass | | 9 | IDR 19,000 110 gr |
| | Control valve | BD | Stainless steel | Brass | | 7, 9, 10 | IDR 27,500 200 gr |
| | Flexible hose | BE | SAE 30 (standard oil and fuel) | PU (standard pneumatic) | | 7 | IDR 7,600 20 gr |
| | Hose clamp | BF | Stainless steel thread clamp | Spring hose clamp | Cable ties | 7, 9 | IDR 3,000 30 gr |
| Catalytic cleaning system (VC3) | Cap tube | CA | Stainless steel | Alumunium | PVC | 7, 9 | IDR 17,000 200 gr |
| | Nipple and silencer | CB | Stainless steel | Brass | | 9 | IDR 23,000 130 gr |
| | MPCF | CC | Stainless steel | Brass | Pneumatic standard plastic | 9 | IDR 34,100 90 gr |
| | Elbow fitting | CD | Stainless steel | Brass | Pneumatic standard plastic | 9 | IDR 3,500 10 gr |
| | Control valve | CE | Stainless steel | Brass | | 7, 9, 10 | IDR 23,350 100 gr |
| | Elbow MSL valve | CF | Pneumatic standard plastic | | | 7, 9, 10 | IDR 10,000 30 gr |
| | Tube hose | CG | Alumunium pipe | SAE 30 (standard oil and fuel) | PU (standard pneumatic) | 7, 9 | IDR 8,400 10 gr |
| | Flexible hose | CH | SAE 30 (standard oil and fuel) | PU (standard pneumatic) | | 7, 9, 10 | IDR 7,600 20 gr |
| | Hose clamp | CI | Stainless steel thread clamp | Spring hose clamp | Cable ties | 7, 9 | IDR 1,500 15 gr |
| Air supply | Regulator pressure | EA | Regulator pressure no | Regulator pressure | Regulator pressure | 3, 7, 10 | IDR 70,000 600 gr |

| System Structure | Sub Component System | Node | Component Variations 1 | 2 | 3 | Target Spec. | Add. Analysis |
|---|---|---|---|---|---|---|---|
| and | valve | | filter | single filter | double filter | | |
| supporting system | Switching valve | EB | Regular ball valve with tee fitting | 3 way valve | | 2, 7, 9, 10 | IDR 65,000 220 gr |
| (VC4) | Check valve | EC | Reguler valve | 1 way valve | Direct | 6, 9 | IDR 20,000 150 gr |
| | Air compressor | ED | 1/2 hp oiless with 25 lt tank | 3/4 hp oiless with 25 lt tank | 1 hp oiless with 25 lt tank | 13 | IDR 1,125,000 20,000 gr |
| | Housing case | FA | Acrylic | Poly carbonate | Stainless steel | 4, 14, 15, 16 | IDR 70,000 1,275 gr |
| | Support leg | FB | Telescopic monopod | Telescopic tripod | Leveling tripod | 8 | IDR 785,000 3,500 gr |

$$\begin{aligned} TW\ VC1 &= W\ AA1 + W\ AB2 + W\ AC2 + W\ AD1 + W\ AE2 + W\ AF1 + W\ AG1 + W\ AH2 + W\ AI1 \\ &= 500 + 150 + 410 + 150 + 220 + 360 + 735 + 300 + 90 = 2{,}915 \end{aligned} \quad (10)$$

$$\begin{aligned} TW\ VC2 &= W\ BA3 + W\ BB1 + W\ BC2 + W\ BD1 + W\ BE2 + W\ BF1 \\ &= 650 + 150 + 110 + 200 + 20 + 30 = 1{,}160 \end{aligned} \quad (11)$$

$$\begin{aligned} TW\ VC3 &= W\ CA1 + W\ CB2 + W\ CC2 + W\ CD3 + W\ CE1 + W\ CF1 + W\ CG3 + W\ CH2 + W\ CI1 \\ &= 200 + 130 + 90 + 10 + 100 + 30 + 10 + 20 + 15 = 605 \end{aligned} \quad (12)$$

$$\begin{aligned} TW\ VC4 &= W\ EA3 + W\ EB2 + W\ EC3 + W\ FA1 \\ &= 600 + 220 + 150 + 1.275 = 2{,}245 \end{aligned} \quad (13)$$

$$\begin{aligned} TW &= TW\ VC1 + TW\ VC2 + TW\ VC3 + TW\ VC4 \\ &= 2{,}915 + 1{,}160 + 605 + 2{,}245 = 6{,}925\ gr = 6.9\ kg \end{aligned} \quad (14)$$

The measurement results regarding Total Weight obtained a value of 6.9 kg, which is around 1.4 kg heavier than the total weight of products on the market (approx 5.5 kg see Table 3), this is because the multi feature engine carbon cleaning tool prototype has a housing case which increases the weight of the tool but provides durability, compact and practicality for the tool. Next, to test the durability, an load test is carried out the carrying capacity of the housing case to support the weight of the entire component that makes up the tool. The test is simulation-based using Von Mises stress analysis. The color representation of the simulation results shows the ability to withstand the load, the redder it is, the less capable it is and the bluer it is, the more capable it is. Figure 4 shows quite good results where the blue color represents the housing case is able to withstand the total load of all the components that make up the tool, so it can be said to be feasible.

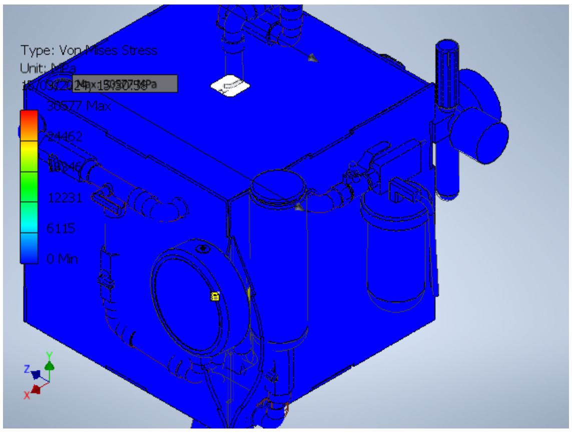



**Figure 4.** Von Mises Stress Analysis of Housing Case Engine Carbon Cleaning Maintenance Tools

*c. Prototyping*

This stage is the final stage where a physical prototype of the product design is created and optimization of the design development that has been carried out. Figure 5 shows documentation of a physical prototype that has been successfully realized so that it can then be actual tested on Figure 6.

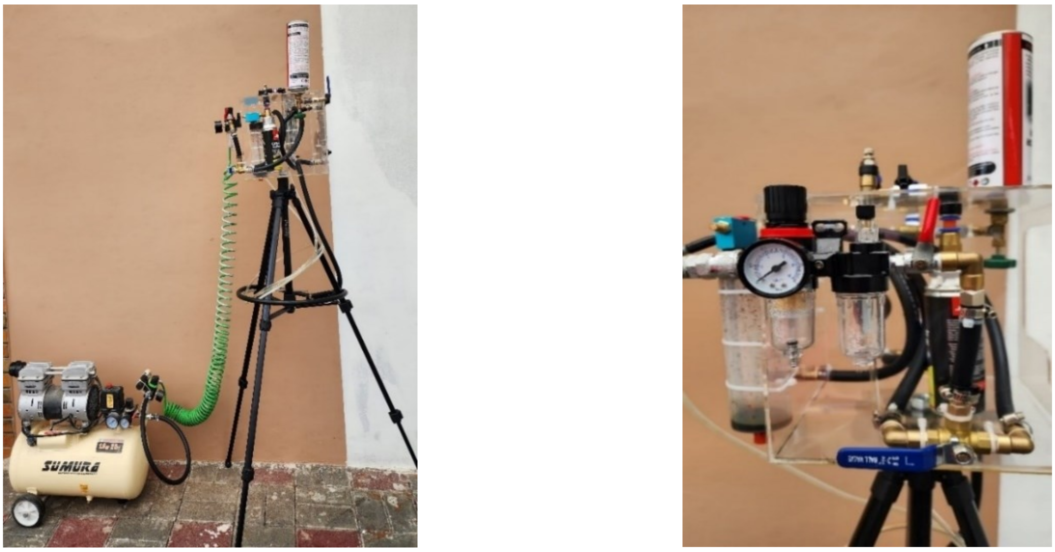


**Figure 5.** Physical Prototype of Multi-Feature Engine Carbon Cleaning Maintenance Tools

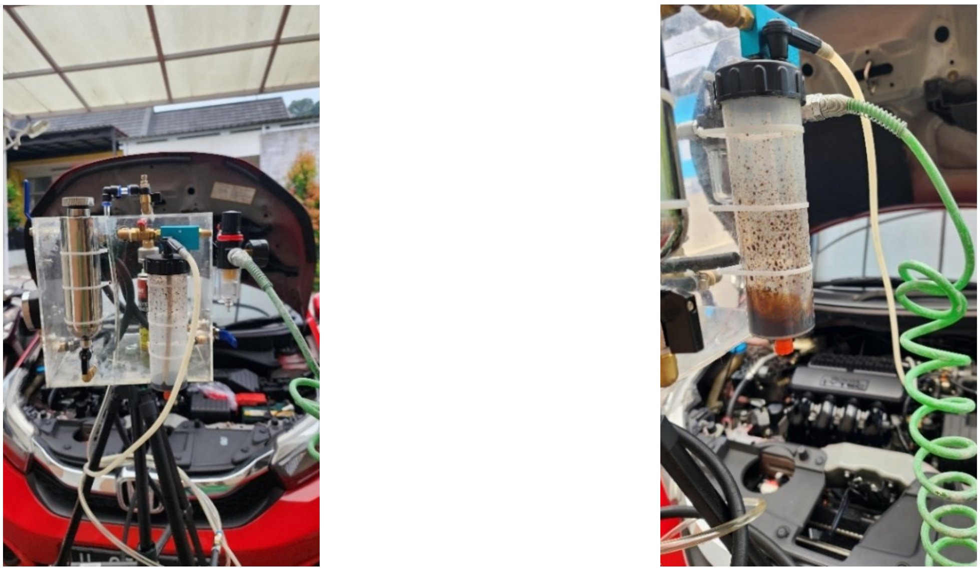
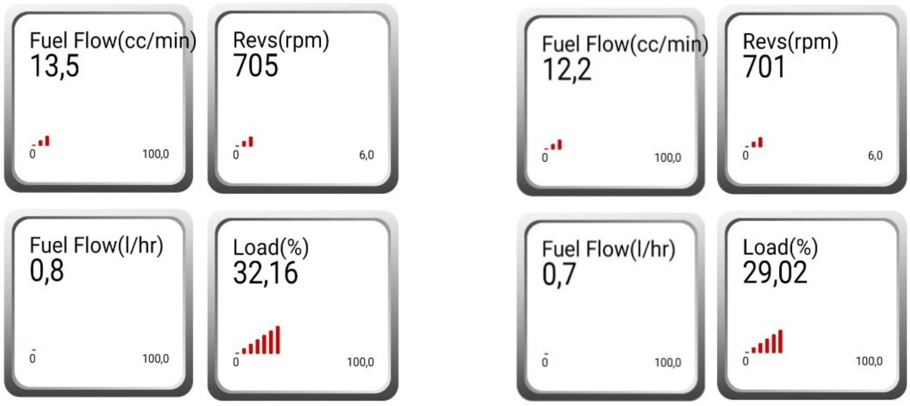


**Figure 6.** Prototype Actual Testing of Multi-Feature Engine Carbon Cleaning Maintenance Tools

After making a prototype and actually testing the prototype on a limited scale on four-wheeled vehicle objects with a petrol engine vehicle that is the last 5 years old, test result data will be obtained to support the effectiveness of the design of the tool. Proses pengujian dilakukan dengan penggunaan alat tersebut untuk proses injector cleaning, combustion chamber cleaning dan catalytic system cleaning sekaligus menggunakan 1 alat yang telah dirancang. Test results were measured actually on a limited scale using an OBD2 engine scanner with injector fuel flow and engine load parameters. Figure 7 is a parameter measurement using an OBD2 scanner device which is measured from conditions before and after use in idle RPM engine condition.




(a) (b)

**Figure 7.** OBD2 Scan Results of Tools Testing (a) Before (b) After

## 4. DISCUSSION

Through the application of the Reverse Engineering method, product design and development results were obtained that took into account 14 consumer needs. Using the VDI 2222 (Verein Deutcher Ingenieure) method in optimization, determining variations in the concept in further research can be developed through other variation concepts (VC) with more varied working mechanisms and constituent components and still maintaining the target specifications of the tool being developed. As a reference for further research, optimization can be carried out regarding the air compressor power requirements to support the air supply system and center of gravity of the multi feature engine carbon cleaning maintenance tools. Apart from that, tools operational costs can also be calculated and optimized to support efficiency. Furthermore, at the testing stage the prototype can also be tested using liquid chemicals of various brands and optimized through tool settings and can apply various test parameters including NOx, CO, CO2 emission tests, engine performance test horse power (HP) and torque in high RPM engine condition.

## 5. CONCLUSION

This research is proven to be able to apply the integration of Reverse Engineering and VDI 2222 (Verein Deutcher Ingenieure) methods in the design and development optimization process of multi feature engine carbon cleaning maintenance tools. The research results show that the total cost of making the tool is IDR 1,137,900 with a total tool weight of 6.9 kg (excluding air compressor and leveling tripod), which is more economical than the total price of injector cleaning tools, combustion cleaning tools and catalytic cleaning tools available on the market. Carbon engine maintenance tools, which were previously separated according to the type of component cleaning, can now be available in just 1 tool. Furthermore, this tool also provides a tripod leveling feature where the height can be adjusted according to the height of the vehicle's engine, and has an elevation level feature which can detect the slope of the floor so that the top of the tool can be balanced. The actual test results of the tool show that it is able to meet 14 types of consumer needs with limited scale test results in idle vehicle engine conditions, able to save fuel consumption (depending on the liquid chemical used) by ±12.5% per hour with engine workload which can also be reduced by 3.14%.

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