Compressed Air Engine

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Abstract-Mankind is always looking for efficient and pollutant-free way of powering their machine. Resent development in light and strong material has aided us to achieve those easier ways. In present study a 4 stroke engine was modified into 2 stroke engine, and was used to run on compressed air technology. Some test was performed on the modified engine to study the effectiveness of the engine.

Index Terms- Compressed air Technology, Valve, Compressed air Tank, Heating filament.

I. INTRODUCTION

The present situation of depletion in fossil fuel and high rise in price of gasoline has forcedresearchers to find other sources of energy to replace fossil fuel.Some presented the idea of electric motor, hybrid engine and newly developed Compressed Air Engine (CAE). A Compressed Air Engine is a type of engine which uses compressed air technology to generate useful work output. The idea is to store compressed air inside a tank. The compressed air inside the tank has large amount of energy, and this energy can be used to move the piston of an engine. The back and forth movement of piston inside the engine cylinder results in generation of useful work energy.

II. History

The history of Compressed Air Technology (CAT) is not new to industries. Pneumatic pressure stored in tanks with the use of CAT has been used to drive many pneumatic based devices in industries. The use of CAT did not remain to just industrial application but has been also applied for driving the vehicle. CAT was first used for running a vehicle in 18thcentury (Mishra & Sugandh, 2014, p. 99). The energy from the CAE was used to power a train by Tramway de Nantes in France (Mishra & Sugandh,2014, p. 99). The use of CAT to power an engine did not earn much audience due to some technological disadvantages and the easy availability of gasoline. However, Charles B. Hodges not only invented a car to be powered by a compressed air engine but also achieved success in finding great use for commercial industries (Mistry Manish K, Rathod,&Arvind, 2012, p. 271).Charles work on CAE brought a possibility to use CAE in small cars. In 2002 an engine with two stage was developed by Motor Development International (MDI) to easily fit inside a commercial car (Thipse, 2008). This engine overcame many disadvantages of early CAE engines and was more efficient in working. The engine developed by MDI also has a greater value of torque when compared with early CAE engine. Further, the Indian motor giant TATA announced to manufacture CAE powered car, with hopes of offering it directly to consumers, in 2018 (Lampton, p. 4). The work on the current CAE still need to overcome some disadvantages of recharging the compressed air tank. Big carmakers are still waiting for some major development in the

CAE based car before putting their hand in the production of such car (Lampton, p. 4).Hence, the co-development by MDI and TATA give the new possibility of powering a car with CAE.

III. Parts of CAE

A new generation Compressed Air Engine consist of highly engineered parts to ensure smooth running and high efficiency. The design of CAE consists of compressed air tank, throttling valve, piston engine and exhaust tail. The car will have an inbuilt compressor which will use the surrounding air to refill the compressed air tank (Lampton, p. 4). A compressed air tank is very important part of CAE. A compressed air tank is a container where highly pressurized compressed air is stored. Thus, a compressed air tank act like a powerhouse for the CAE and is responsible for driving the piston engine (Lampton, p. 1).The energy inside a Compressed air tank comes from highly pressurized air. However, the increase in the value of pressure inside the container can lead to busting of container (Thipse, 2008, p. 36). It is necessary to build a container with higher strength to sustain such high value of pressure. One such solution is increasing the thickness of the container walls. Increasing the thickness can give the structural strength to container, but at the same time it increases the weight of the container. The increase in weight of the container is not favorable while designing a car. The compressed air is not easy to store in compact vessel while considering the weight reduction of car (Edelstein, 2015, p. 2). Thus, there is a need of some high strength material to design a container (or a compressed air tank), which is light in weight at the same time. According to LeGault (2012)" The higher modulus and fracture toughness afforded by the silica-filled epoxy/carbon fiber composite enables a tank design that weight less but has greater capacity in same footprint" (p. 4). A tank made of carbon fiber will help in avoiding the risk of busting by giving enormous strength and at same time it will be lighter in weight. The carbon fiber compress air tank will have an outlet, passing through the throttling valves, connecting the inlet of the engine.

An engine is a device which convert one form of energy into a useful output work. The basic design of an engine consists of a piston, an engine cylinder, a set of inlet-outlet valve and a crankshaft.According to Mishra& Sugandh (2014), "A compressed air engine is a type of engine which does mechanical work by expanding air" (p. 99). Following the similar footprint of conventional engine, a compressed air engine uses pressure from atmospheric air stored in a compressed air tank as a fuel to provide the require pressure to move the piston.According to Lampton (n.d.), "compressing a gas into a small space is a way to store energy, when the gas expands again, that energy is released to do work" (p. 1). A throttling valve is provided between the compressed air tank and the air engine to check the amount of air flow into the engine from compressed air tank. As the inlet valve opens the engine comes in direct contact with the compressed air stored in the tank. The high-pressure air rushes into the engine chamber for the expansion. According to Thipse (2008), "The expansion of the compressed air drives the piston to create movement, replacing the burning of fossil fuel in a conventional engine" (p.34). The expansion of compressed air takes place when the engine piston is at TDC. The compressed air acting on the surface of piston head leads to the development of high pressure on the piston head.The highlypressurized air passed into the engine chamber pushes the piston and creates the movement of piston from TDC to BDC (Manish, Rathod, &Arvind, 2012).This simple process helpan engine to run in a smooth and efficient way.

An engine for commercial production need to be efficient with high power output. Today consumer want a car which set perfect with their pocket but have the same work power like conventional cars. This can be only achieved by fulfilling to important criteria of the customers: If the energy required to power the car is easily available and is cheaper. The car should have high power and torque. A CAE advantageously meet to the first criteriaof the costumers as it uses the normal surrounding air as a fuel to run the engine.The air around us is in abundant volume and is also free as discussed above. Further, the second requirement of the car buyer is the power and efficiency of the engine to do their required work. An engine is best graded by its efficiency. An engine is always compared with other engine based on its efficiency. Efficiency of an engine means how much output energy it can produces for a given amount of input energy. The energy efficiency of CAE can be given as the ratio of output energy produced by the engine to the input energy applied to the engine (Yu &Cai, 2015, p. 147). Therefore, after successfully fueling the CAE with cheaper energy, the second important task was to obtain higher power output from the compressed air.The basic object of using compressed air technology is to obtain a higher value of work output for considerably less amount of input energy (in form of compressed air) from a CAE (Mishra & Sugandh, 2014, p. 100). The actual power of the engine can be only determined by experimental observation and mathematical calculation. An experiment model designed of CAE shows that when the throttling valve is opened to allow large flow of compressed air into the engine chamber, it result in the faster speed of the car with a highest value of torque output (Wang, You, Sung, &Hang, 2014, p. 64). Thus, this give an experimental proof that a CAE has much better torque to do work like conventional engine. However, the torque generated by CAE keeps on decreasing with the decreasing pressure inside the compressed air tank. Thus, a compressed air need to overcome such disadvantage. On September 15, 2004, Di Pietro came up with a new design CAE which he claimed to be 100% more efficient than any other type of CAE to the date and the torque output was much better to power a car (Hanlon,2004, paragraph 1).This development so far given an opportunity for the car makers to look for a better possibility to power their vehicle with an engine which overcome fuel crises and at the same time stand out to be a greener source of energy.

IV. Global Warming: Present threat to earth

Today the greatest threat to life on earth is global warming. To combat global warming different nations are pushing their researchers and scientists to find out the ways for the energy source which are unlimited and greener at the same time. One such possibility is coming through the development of CAE. A car powered by CAE will have zero value of pollutant emission from its tail which will make it ideal for using in cities which have high level of pollution issues (Manish, Rathod, & Arvind, 2012, p, 1). CAE is believed to claim the podium for the greener way of generating energy. CAE uses the normal air to generate energy. Unlike any conventional combustion engine which uses the combustion of fuel to generate energy, a CAE does not involve burning of carbon-fuel, due to which there is no change in the form of molecules in the intake air. Thus, the air coming out of the engine exhaust is same as the air sucked by the CAE. According to Mishra, &Sugandh (2014), “Without any combustion the motor is driven by the compressed air in which after combustion, dangerous and harmful gases were comes out which results in zero pollution mobility concept ideal for current global warming concerns which makes the environment eco-friendly” (p. 100). CAE can be considered as a breathing engine which just inhale and exhale the air. A clean way to generate energy give an advantage to CAE, such that it can be used to power automobiles to reduce the pollution from their tails (Lampton (n.d.)p. 2). Further, it has been found that the exhaust air coming out of the CAE has lower temperature in comparison to the hot air going inside the engine.According to Thipse (2008), “The temperature of the clean air expelled from the exhaust pipe is between 0 to -10 degree and can be channeled and used for air conditioning in the interior of the car” (p. 36). Thus, the exhaust air from the CAE will be utilized to further obtain the work of cooling without consuming any extra energy.

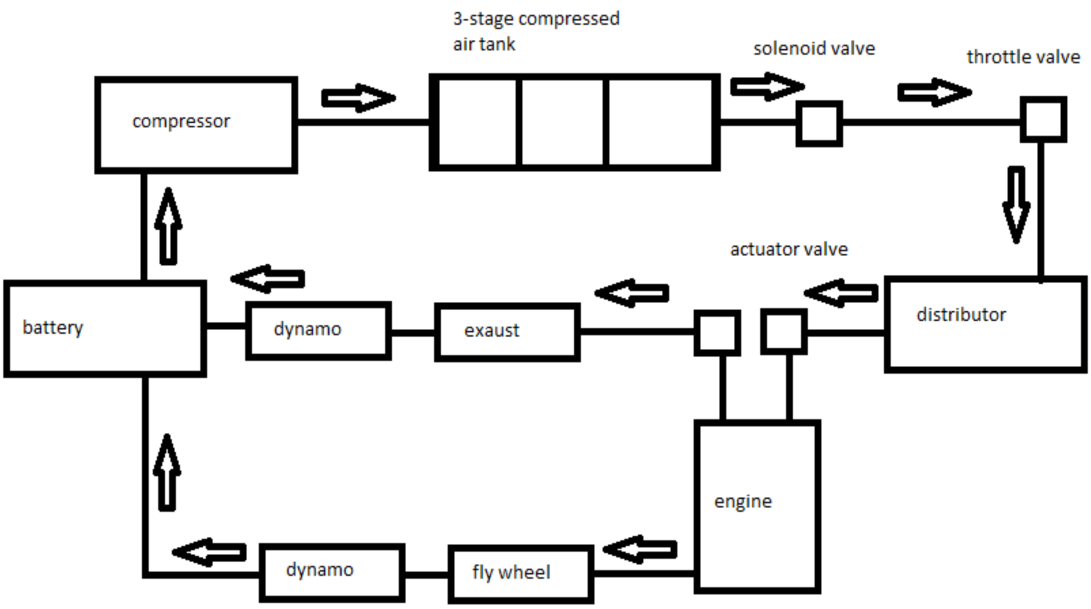
V. Overview of this paper

The review of literature gives a brief introduction to the evolution of CAE; it presents the problemof leakage and inefficiency that are faced while designing the components of CAE and how they can be overcome. Further,it also covers the advantages of using CAE in reducing the energy crises and lowering the global warming. However, the concept of running the car using CAE still need some focus in developing infrastructure to power the car.This paper presents the concept of my CAE design,presents the concept of modifying a conventional 4-stroke internal combustion engine into a 2-stroke engine to run using compressed air technology, presents the basis for my CAE testing, anddiscussesits advantages and give an overview on CAE future development.

VI. The layout of my CAE design

The proposed design consists of systematic arrangement of apparatus to generate energy from the engine in optimized way.

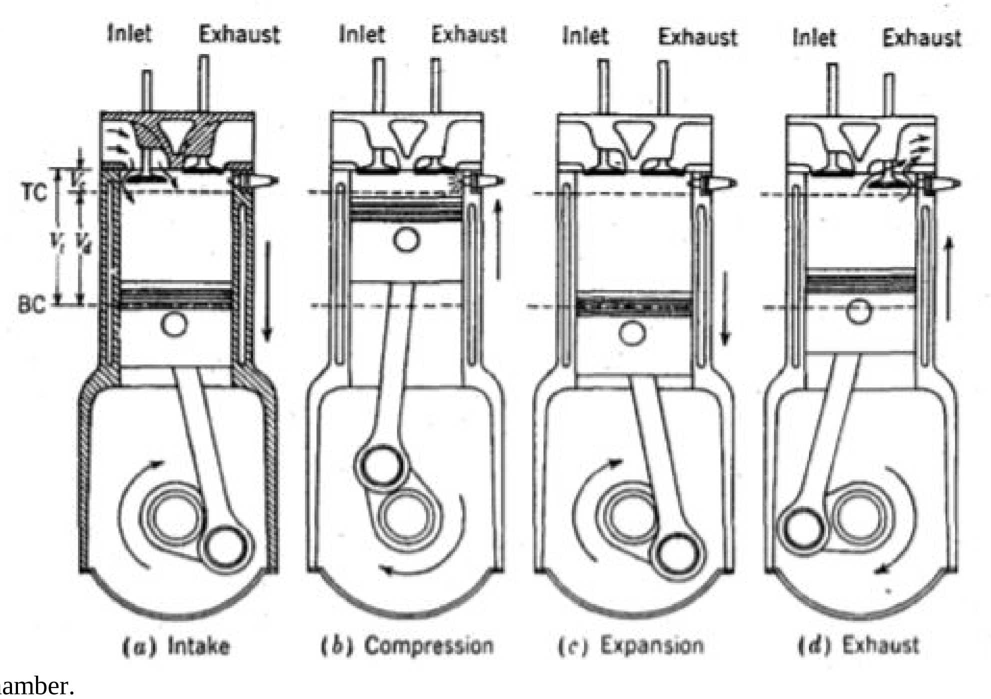
Figure 1: circuit diagram of CAE



The above circuit diagram can be explained as follows:the first engine will be equipped with a compressor to compress the air into the compressed air tank. According to Noh, et. al. (2016), "The optimization of compression part design is the most fundamental and important factor" (p. 44).Thus, designing a CAE car equipped with compressor will aid to the generation of on board compressed air energy to run the car. However, the compression of gas in a tank is a critical and time taking process. According to Krudi, et. al. (2014)," Designing a pressure vessel for extremely high pressure condition is quite complicated and required detail consideration in many aspects including permissible stress level, definition of operation, failures criteria, material properties" (p. 746). Therefore, once the concept of CAE based car catch up with the market, an infrastructure of compressed air station will be installed. The gas station will allow the car driver to fill the compressed air tank within few minutes.Now the compressed air will reach to the 3-stage compressed air tank. It consists of three chambers as shown in the diagram. The air from the compressor will directly enter to the 1st chamber where a certain amount of pressure will reach and the air will go to the 2nd chamber via pressure valve and finally to the 3rd chamber with the same procedure as above. Further,all the chambers are provided by an air-conditioning element which will allow more compressed air to get stored in the same volume of the tank. A main supply line, transport the compressed air withdrawn from the tank further to the engine. In this line, a key-operated solenoid valve is placed which serves as a selective shut off valve to start and stop the engine. Ones the solenoid valve is open, the main supply line delivers the compressed air to the main injectors. This line has a throttle valve arranged downstream which is connected to a mechanical linkage which isoperated by means of accelerator pedal (Lee, Shim, & Kim, 2015, p. 24). Now the compressed air enters the distributor. Since the proposed design consist of a multi-cylinder engine, a distributor is used to channel the compressed air into each cylinder equally. The pipe in the distributor consist of many holes which will be equal to the number of cylinders in the engine, along its length. From the distributor, each hole lead a separate line to transport compressed air to each cylinder of the engine. The compressed air is then injected into each cylinder when the piston is at TDC. The accumulation of compressed air over piston head cases the piston to move from TDC to BDC. The piston in each cylinder rotates the crankshaft connected to it. During this time the compressed air expand and cools down. After the first stroke the piston move from BDC to TDC, this causes the cooled air to exhaust through the mechanically operatedexhaust-valve (as in conventional internal combustion engine). In the proposed design the cylinder will be surrounded by the heating filament which will cause more thermal expansion of compressed air in the cylinder. Increase in the expansion will help in generating high pressure on the piston head and will help to increases the efficiency of the engine.The exhaust air will be passed through the turbo which will rotate the impeller shaft inside it which is connected to the dynamo at the other end. This technique will be used to generate electricity from the waste exhaust air. Batteries will also be charged from the flywheels using the same technique which can be found in almost every vehicle. The batteries charged from Turbo and Flywheel will be used to drive the compressor and the cycle continues.

VII. Modification to CAE

To modify a 4-stroke engine into a 2-stroke engine, it is important to understand the working concept of a 4-stoke internal combustion engine. As the name implies, a 4-stroke engine consist of 4 different stoke, namely suction stroke, compression stroke, power stroke, and exhaust stroke. A stoke is defined as the as the distance travel between TDC and BDC (Shi, Jia, Cai, & Xu, 2015, p. 2). An internal combustion engine also consists of two stoke synchronize valve i.e. inlet valve and outlet valve. (Heywood, 1988, p. 10-11) An inlet valve controls the flow of air-fuel mixture inside the engine chamber and an outlet valve controls the flow of exhaust burned gases out of cylinder chamber. The first stroke of an ideal internal combustion engine startwhen the piston is at TDC (Heywood, 1988, p. 10). At this point the inlet valve of the engine also start opening. During the suction stroke the piston move from TDC to BDC, this movement of piston causes the decrease in pressure over the piston head and creation of suction. Thus, when the inlet valve opens during the suction stroke, the air-fuel mixture get sucked inside the engine chamber. The second stroke start when the piston is at BDC (Heywood, 1988, p. 10). At this point the inlet valve of the engine get closed and it remain closed till the next end of forth stroke. During the compression stroke the piston moves from BDC to TDC. The movement of piston from BDC to TDC causes the air-fuel mixture to compress and increase of the pressure inside



the engine chamber.

Figure 2: four strokes of engine(Heywood, 1988, p. 10)

The third stroke start when the piston is again at the TDC (Heywood, 1988, p. 10). At this point the ignition of the air-fuel mixture is triggered by the spark plug inside the engine chamber. The ignition of the air-fuel mixture causes a sudden increase of pressure inside the engine chamber. This high-pressure act over the piston and pushes the piston from TDC to BDC. The movement of piston causes generation of output power from the engine due to which this stroke is known as power stroke. The forth stoke start when the piston is at BDC (Heywood, 1988, p. 10). At this point the outlet valve of engine also start opening.

During exhaust stroke the piston move from BDC to TDC, this movement of piston pushes the burned-out gasses out of engine chamber through outlet valve opening. The outlet valve just opens for exhaust stroke. In internal combustion engine, the lower end of the piston is connected to the crank shaft. For every stroke of piston, the crank shaft rotates for 90° (Heywood, 1988). Thus, the crank shaft rotates for 720° (or two complete revolutions) during the 4-stroke of the piston (Heywood, 1988). This means in four-stroke engines, a single power stroke is produce every 4th stroke. Where as in two stroke engines, a power stroke is produced on every 2nd stoke.These all design mechanism were considered while modifying a 4-stroke into 2 stroke engines (Heywood, 1988, p. 10-11).

In the current design, a 150cc 4-stroke spark ignition internal combustion engine was used. To modify this engine into 2-stroke and run it with CAT, modification was done by changing the timing gear configuration of cam shaft, inlet nozzle and valve timing of the engine. The design of engine is a basic 4 stroke engine but, instead of getting a power stroke in alternative revolution this engine was modified to obtain a power stroke in every revolution of the crank shaft.First, modification of cam shaft: originally the cam shaft was designed to run on a four-stroke engine with the opening and closing of an outlet valve at first and fourth stroke respectively. This designed was modified to close and open the inlet and outlet valve at every 1800 revolution of crank shaft. Second,modification of timing gear:The speed ratio of timing gear to the crank shaft gear was modified from 2:1 to 1:1, thus providing an equal revolution to the timing gear with respect to the revolution of crank shaft which leads to the conversion of 4-stroke engine into a 2-stroke engine. Third,modification of inlet valve: the carburetor of engine valve is removed and an inlet nozzle is provided so that the outlet of compressed air tank can be connected to the Compressed Air Engine. Fourth, modification of inlet and outlet valve spring: the carburetor of engine valve is removed and an inlet nozzle is provided so that the outlet of compressed air tank can be connected to the Compressed Air Engine. Fifth, the stiffness of the springs used in the valves was removed.

VIII. Testing

This paper presents the testing of modified engine. The experimental test conducted on the CAE engine developed in this paper give a practical feasibility of the theoretical concept. The modified engine was tested by using a two-cylinder piston compressor at different values of compressed air pressure.

Table 1: test result

Test	1
Date	06/12/2014
Test condition	• Inlet compressed air pressure: 150 psi • No coolant was used. • No engine oil was used. • No spark plug was used. • Engine was manually started

	• Normal weather conditions
Modification	No modification
Results	Engine just took only one stroke and stopped automatically

Table 2: test result

Test	2
Date	06/18/2014
Test condition	• Inlet compressed air pressure: 150 psi • No coolant was used. • No engine oil was used. • No spark plug was used. • Engine was manually started • Normal weather conditions
Modification	Inlet and outlet valve was modified by reducing the stiffness of the inlet and outlet valve spring
Results	• Cool air was coming at the exhaust outlet • Engine was started and was running successfully

Table 3: test result

Test	3
Date	06/23/2014
Test condition	• Inlet compressed air pressure: 120 psi • No coolant was used. • No engine oil was used. • No spark plug was used. • Engine was manually started • Normal weather conditions
Modification	The Compressed air pressure was reduced from 150 psi to 120 psi
Results	• Cool air was coming at the exhaust outlet • Engine was running successfully

The experimental results conclude that the 4-stroke engine was successfully modified to 2-stroke engine and the engine was running perfectly on Compressed Air.

IX. Advantages of CAE

This paper discusses the advantages of CAE and give an overview on CAE future development. According to Brown, Atluri, &Schmiedeler (2014), “Compressed air energy storage(CAES) system are one potential alternative to battery-electric system due to their high-power density, low cost, and minimal environmental impact”(p. 477). Thus, theuse of CAE can provide an alternative to electric cars. The experiment shows that there is no emission of pollutant particle from the engine exhaust. As CAE includes no burning of fuel there is no conversion air molecules into other molecular structure (Mishra &Sugandh ,2014, p. 99). Hence, CAE stand out to be an eco-friendly engine with zero emission. Also, the fuel used in CAE is compressed form of natural air, which is used to power the engine and emitted in same natural form, so there in depletion in the source of fuel. Further, it was found in the above experiment that a CAE does not require any coolant. Since there is no combustion taking place inside the CAE, a CAE does not require to be cooled to maintain its structural strength. A CAE is very simple in its working process, this means it does not require a complex arrangement of spark plugs, cooling system, and turbos. Thus, a CAE has less costly parts compared to an internal combustion engine. Further, it was found in experiment that the exhaust air coming out of the engine was cooler. This means the cool air coming out from the CAE can used to chill the passenger compartment of the car.The CAE engine is also cheaper in running. A CAE only use natural air as a fuel which is free and abundant in nature. The money required in running the engine is for compressing the air, which is a cheap process. Thus, a CAE is very advantageous in use.

The initial design ofCAE shows positive results in the development of CAE based car. However, it need several improvements in its design to catch up with current market requirement.According to Zang, Liu, Li, & Wu (2013) “Compressed air usage, shortage, leakage, and efficiency are several factors that influence the efficiency of a compressed air system” (p. 52). Therefore, an overview of the proposed future design of CAE is presented.The cylinders of the CAE will be surrounded by electronic heating filament. The heating filament will produce more expansion in the cylinder which will generate high pressure and increases the efficiency of engine. Also,the exhaust air will pass through the turbo which will rotate the impeller shaft inside it which is connected to the alternator at the other end. This technique is used to generate electricity from waste exhaust air. Further, this exhaust will be used for air conditioning and as inter cooler into the compression cycle. The batteries charged from the turbo and flywheel will be used to drive the compressor, this will help in generating on board compress air to fuel the engine. A Compact and high pressure holding carbon fiber compressed air tank will be used which will provide high strength to the compressed air tank and at the same time lighter in weight. A Multi cylinder Compressed Air Engine will be also introduced, which can generate more power for heavy duty work.

X. Conclusion

The paper present the theoretical concept of designing an engine which can run on compressed air technology. Here the theoretical concept was also experimentally proved by modifying a 4-stroke engine into a 2-stroke engine and running the engine by proposed compressed air.Further the experimental result was presented which showed the advantages of using CAE. Thus, A CAE give a possibility to use the unlimited resource of air as a fuel to run the engine. The proposed concept design of CAE helps in solving the problem using a fuel which is renewable and at the same time cheaper in use. The paper also present an overview on the proposed future development of engine for making it more efficient for public use.

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