AEA Energy & Environment
From the AEA group

Work on Preparatory Studies for Eco-Design Requirements of EuPs (II)

Lot 17 Vacuum Cleaners

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Task 6 Report

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1 Task 6 Technical Analysis BAT

This section looks beyond products that are currently on the market to consider what products might be available in the future. While the detail of how both the energy and cleaning efficiency of vacuum cleaners can be improved is the responsibility of the manufacturer, there are some general techniques that can be applied for improving the efficiency of the different types of vacuum cleaner. Although they are all theoretically possible, some will be unrealistically expensive to implement. Costing of modifications is not attempted, since the expense will vary with vacuum cleaner type, size, materials and existing individual design details. The examples in this section should not be generalised.

1.1 State of the art in applied research for the product (prototype level)

1.1.1 History

The electric vacuum cleaner is a relatively mature product that has been under development for a little over 100 years. The suction only vacuum cleaner, with passive nozzle, first appearing in Europe by 1900 and the vacuum cleaner with rotating brush roll, or agitator, also known as "Upright", first appearing in the USA in 1908. However the designs of the early 21st century would still be familiar to the original inventors with motor technology being largely unchanged and the use of centrifugal fans as vacuum generators still the only technique being used.

The use of cloth bags for collecting and filtering dirt has been augmented by disposable containers, rigid reusable dirt collection receptacles, separate barrier filters as well as non barrier filters such as cyclones.

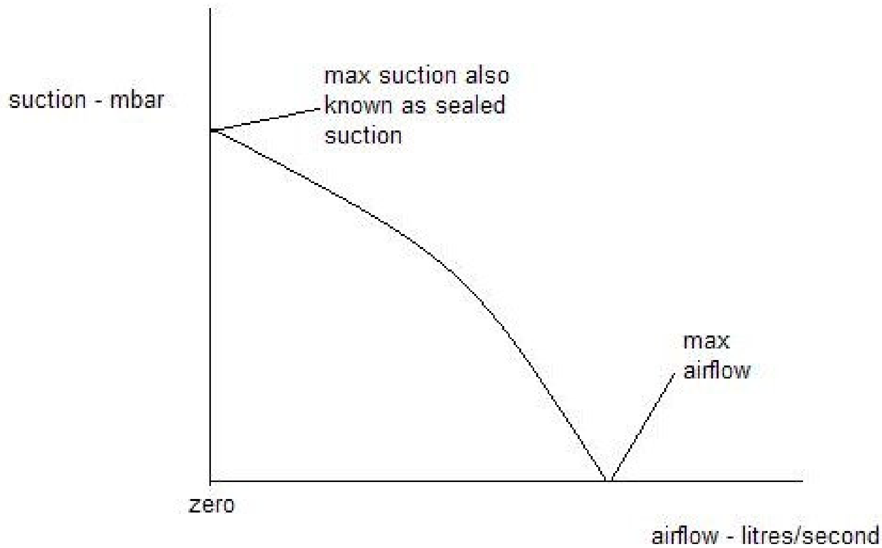
Motor input power was limited to less than 1000 watts until the late 1970s but has since increased significantly to well over 2000 watts, Tesco stores has recently sold a 2700 watt vacuum cleaner in the UK.

The design of passive suction nozzles is still similar to what it was 100 years ago.

The basic design of agitators, to remove surface and embedded dirt is also similar now as to when it was first introduced. The main changes being the introduction of plastics for the rotating cylinder and man made fibres replacing horsehair for the bristles. Whereas both brushes and beater bars used to figure on an agitator, nowadays only brushes tend to be used. In some cases a separate motor is used to drive the agitator so it can easily be switched off for cleaning certain surfaces.

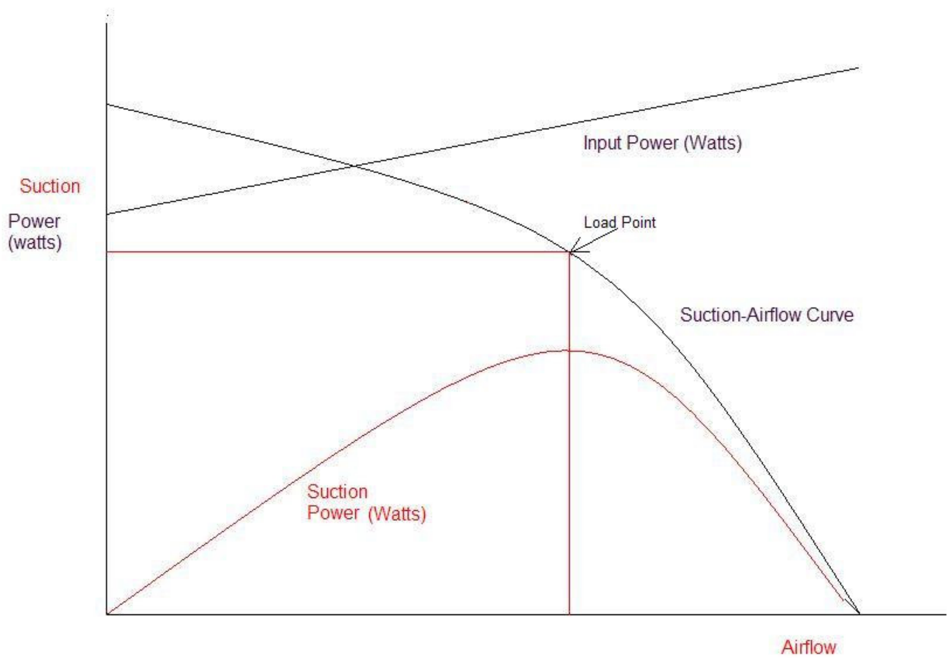
1.1.2 Suction power

Suction power is required to remove dirt from surfaces and transport the dirt to a receptacle, where it can be stored until emptied. Suction power is a combination of airflow and suction and is measured in watts. The following curve shows the relationship between suction and airflow on a typical vacuum cleaner.



Typical suction/airflow curve for vacuum cleaner

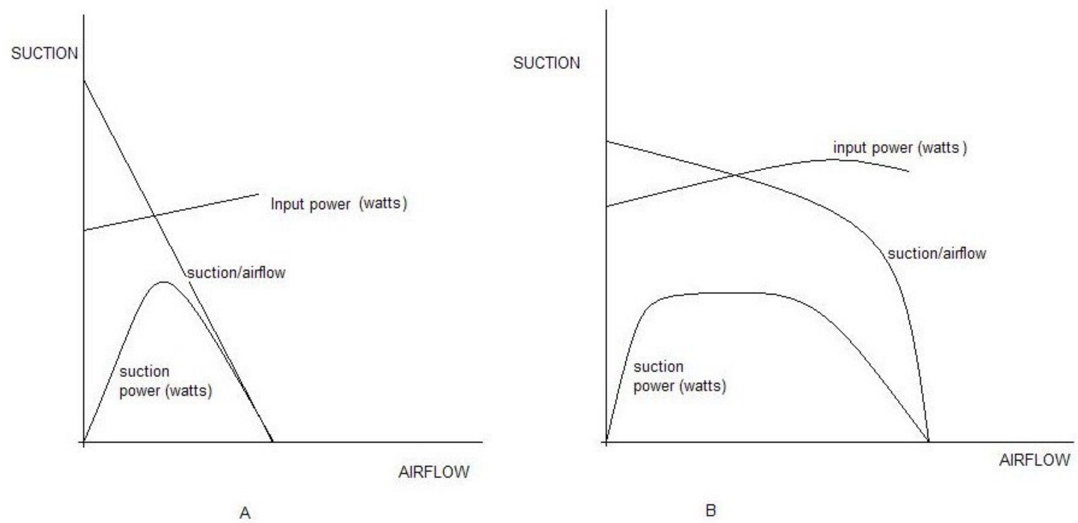
The following curves show the effects of input power and suction power, which is a combination of suction and airflow.



SUCTION-AIRFLOW CURVES

The efficiency of conversion from electrical power into suction power can be extracted from these curves and is the ratio of suction to the input power (both in watts) multiplied by 100. It can be seen that both suction power and therefore efficiency will vary between zero and a maximum at peak suction power. Normally when suction power is quoted for a vacuum cleaner it is the highest or peak suction power and the energy conversion efficiency is usually quoted at the same point. This point is also known as the “load point” and when extrapolated to the key suction airflow curve, as shown, both the suction and airflow at this point can be read off. These are the parameters the vacuum cleaner designer seeks to achieve when the cleaning nozzle is on the surface to be cleaned. This is all particularly true for suction only canister cleaners with passive nozzles. For a vacuum cleaner, which uses an agitator to remove soil from the surface, it is less critical but nevertheless should also factor into the agitator nozzle design

The electrical and torque characteristics of the motor can be tuned to help produce a suction airflow curve that is more bowed outwards and also tends to move the peak suction power closer to maximum airflow. The fan design also contributes to this feature. It is quite possible to achieve a high suction power value, especially when high input powers are available, however it is more difficult to achieve a sufficient level of suction power spread over a longer range. The following curves show, firstly, a vacuum cleaner with high maximum suction but with a relatively low maximum airflow. In this case the motor has higher torque at the highest speeds but as the airflow increases the torque falls away. The second set of curves show what happens when motor characteristics are more closely matched to the additional torque required at higher airflows. In this case the maximum suction power is below that of the first example, however good suction power levels exist over a much greater range of airflow and this can help significantly in producing good cleaning performance over a wide range of surfaces and receptacle/filter dirt levels.



Vacuum Cleaner "A" has higher suction and higher maximum suction power than cleaner "B". However the characterisitics of the motor and the fan system of "B" will allow the performance load point to be extended over a greater range and thus lead to portentially better overall cleaning performance.

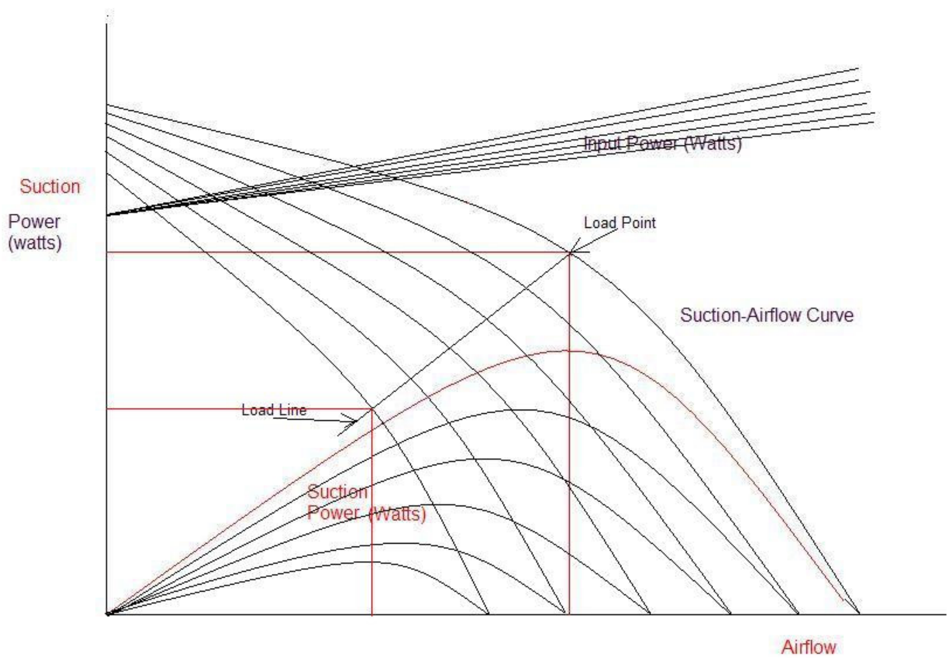
1.1.3 Energy efficiency

Historically, centrifugal fans have been used to create suction power and, in the configuration used, tend to be relatively inefficient at energy conversion. The maximum efficiency can be as low as 15% and has seldom been greater than 50%. When the leaks and inefficiencies of the vacuum cleaner and its connecting tubes and filters are taken in to account the overall energy conversion capability of a vacuum cleaner can be anything between 10% and 33%. It should be emphasised that this energy conversion efficiency has no relationship with cleaning efficiency or ability to pick up dirt where absolute levels of suction, airflow and suction power are more critical.

1.1.4 Filters

In order to prevent dust and dirt from re-entering the atmosphere vacuum cleaners require filtration. Filters are positioned either in the surface of the receptacle containing the dirt, if it is a disposable type, or immediately after the receptacle if the filters are reusable. As an alternative, or in addition, cyclones can be used as a non-barrier form of filtration and these may even form part of the dirt receptacle itself. Barrier filters, hold dust and dirt on their surfaces and within their media. Poorly designed filters tend to clog and cause a reduction in airflow and also suction power throughout the vacuum cleaner and at the cleaning nozzle. Even well designed filters with high dust loading materials being used, and even cyclones in some cases, may also tend to reduce airflow when dust becomes lodged within and on them. A well-designed vacuum cleaner overcomes this hurdle, to a degree, by designing the motor fan characteristics and the cleaning nozzle configuration to always ensure that cleaning takes place at the point of peak suction. This can be seen in the following set of curves.

As the airflow is reduced by filter “clogging”, the suction airflow curve shrinks back towards the zero point and a new suction power curve can be plotted; also the input power tends to reduce. The main design idea is to ensure that the cleaning nozzle is always at the optimum suction power level for each reduction in overall suction and airflow. This is known as the load line. The suction and airflow can reduce to a point where cleaning is significantly affected and the designer should ensure that this point is always well below the normal full receptacle condition of the vacuum cleaner



SUCTION-AIRFLOW CURVES

1.1.5 Rotational speed

To complete the technical understanding and improvement potential it is necessary to understand one more factor and that is the effect of motor and fan speed. Perversely, as the airflow increases the motor fan speed reduces, this is a resultant of the increased load on the motor due to more air flowing through. The electrical characteristics of a universal motor are not able to match the increased load, depending on the actual torque characteristics of the motor. This causes the motor to slow down despite an increase in input power. Conversely, as airflow reduces, the motor speed increases until no airflow is passing through and maximum rotational speed is reached. This point is known as “sealed suction" and is when the maximum suction is reached. For a clean or indirect air vacuum cleaner this represents a potential danger for the motor. Despite the input power being at its lowest it is still significant and there is no airflow to cool the motor. Safety requirements determine that if the motor temperature gets too high either a cut out will operate or a bleed valve will open. At the higher airflows and therefore higher input there is more air passing through to keep the motor cool. A dirty or direct air vacuum cleaner motor needs a separate cooling fan and, ironically, it is at the higher inputs that this fan is running slowest and therefore it must be designed to provide sufficient cooling air at lower speeds which has the further implication of passing more air than is necessary at lower airflows and higher suction levels (higher motor speed) which will therefore use more input power than necessary for the level of suction power. The percentage reduction in energy conversion efficiency due to this is small however, less than 1%.

1.1.6 Agitators

An agitator also rotates and is normally driven by the same motor driving the fan. Agitator speeds are important as they produce a vibration as well as a brushing action. Typically speeds of around 3000rpm produce the best cleaning effect through vibration and brushing. Gearing between motor and agitator is important and since a belt drive is normally utilised shaft diameters are critical when speed differences are of the order of 10:1.

1.1.7 Motors

1.1.7.1 Universal Motors (Wire wound on laminated steel armature and field former, with carbon brushes and commutator).

This type of motor has been used in virtually every vacuum cleaner ever made. It is reliable, versatile, durable, cost effective, easy to manufacture and can be simply tailored by varying wire diameters, coil sizes and coil numbers to produce the torque characteristics necessary to drive a vacuum generator for optimum effectiveness. It can be made in sizes and weights suitable for use in the whole range of vacuum cleaners from battery operated to mains canister and upright types. It is also suitable to drive agitators independently of the main motor.

These motors generally have a high efficiency in converting electrical energy to mechanical (rotation) energy**,** 95% being typical. Improvements in bearings, windings and commutation have resulted in higher motor speed being achieved over the past 20 years. Typically up until the 1970s maximum motor speeds were limited to 30,000rpm, the latest universal motors are capable of speeds up to 40,000. The speeds at maximum suction power have increased from 25,000 rpm to around 32,000rpm. Losses are slightly higher at such speeds due to air friction and bearing losses but this reduction is measured as less than 2%. One benefit of higher speeds is the ability to reduce the number of fan stages (see 6.1.2).

Inherently this type of motor produces a certain amount of noise caused by the carbon brushes maintaining contact with the rotating commutator. However it is not excessive and can be controlled to a degree by accurate manufacture and the use of surrounding noise absorbent materials if required. As the carbon brushes wear down over the life of the motor, usually in excess of 500 hours use, the carbon dust produced can enter the environment unless restrained by specific motor filtration.

Normally, in the domestic market these motors are not considered serviceable and thus, once the carbon brushes have worn out the motor is "dead". Commercial vacuum cleaner motors are usually designed to allow for carbon brush replacement and thus motor life can be extended by at least 3 times. Armature bearings would normally be expected to last for at least the life of the brushes and usually would continue to be serviceable long after that. Self-aligning sleeve bearings are used in suction only motors but ball bearings may well be used if the motor is also used to drive the agitator, particularly at the drive end.

1.1.7.2 A.C. frequency controlled brushless Motors (Wire wound field assembly, magnetised steel armature)

Normally this type of motor has been used in washing machines, it tends to be heavier than a universal motor and its speed is controlled by the number of poles it is given. A two-pole motor will rotate at 3000 rpm in a 50 Hz environment and 4-pole at 6000 rpm, for example. Whilst some consideration has been given over the years for the use of this type of motor it is generally considered to be too heavy and too large to fit into a vacuum cleaner. It is also considered to be less versatile in matching fan characteristics in producing airflow. It may well be quieter than a universal motor but it is more expensive, at least 50% more so as well as being heavier and is unlikely to have a role in domestic vacuum cleaner usage.

1.1.7.3 Electronically controlled brushless Motors (Switched Reluctance)

This type of electric motor has been developed during the past 15 years and has already found uses in vacuum cleaners. It is potentially quieter than a universal motor as it does not utilise carbon brushes in contact with a commutator, although electronic “noise” can be quite high. It works by switching the current flow electronically rather than “mechanically”, via a commutator and uses permanent magnet materials for its armature. Electronic switching is inherently faster that the “mechanical” switching between armature coils via a commutator on a universal motor and this results in speed up to 100,000 rpm being achievable. Higher speeds also lead to smaller motors and fans being required as well as better torque characteristics being possible.

The negative aspect for this type of motor is that costs are significantly higher than for the universal motor, although they are likely to reduce if production volumes increase substantially. From an environmental aspect, materials used in the electronic circuitry and also for the permanent magnets need to conform to present and future materials directives. There is no evidence that, at present, there is any problem with those materials

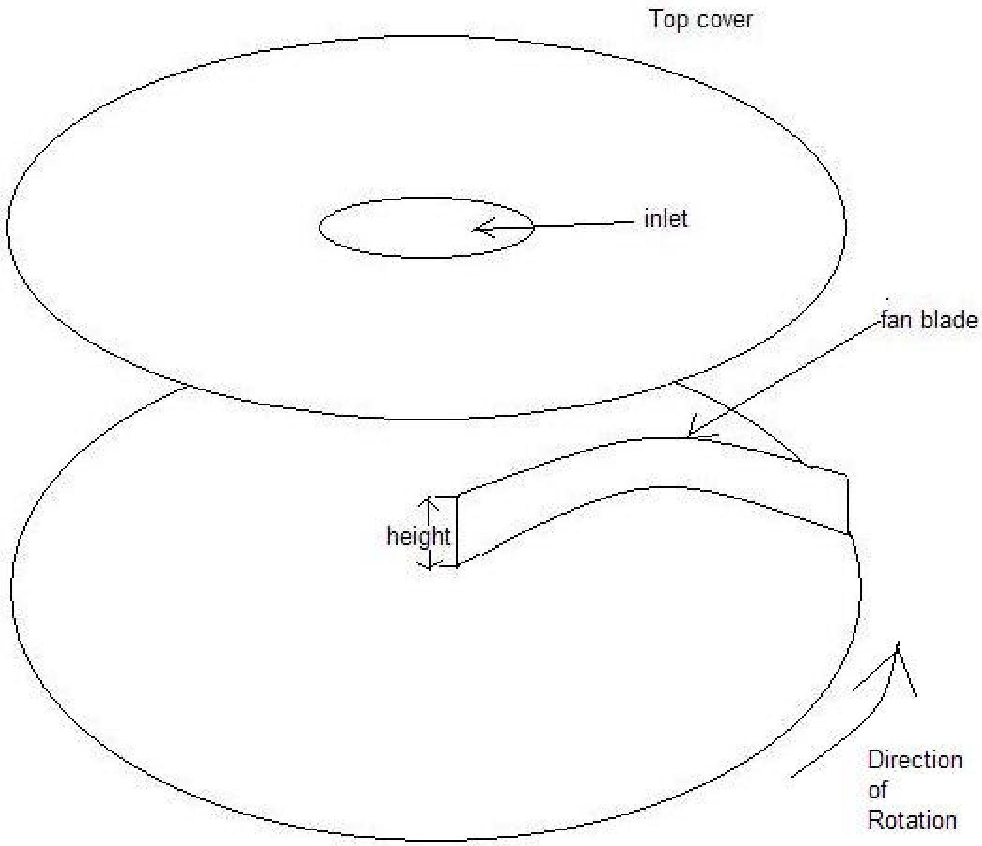
1.1.8 Suction and Airflow Generation

1.1.8.1 Centrifugal Fan Systems

1.1.8.1.1 Single stage

Centrifugal fans produce airflow by rotation of an impeller with curved vanes or blades which guide and drive the airflow to the periphery of the impeller or fan, as it rotates, in such a manner that, when it emerges it has velocity and direction which is close to tangential to the impeller. As the air passes across the fan it creates a lower pressure at the inlet that “sucks” in more air to continue the flow.

In simple terms the height of the fan blades is proportional to the amount of airflow and the diameter proportional to the amount of suction, see sketch below.



schematic exploded view of centrifugal fan assembly. There will be multple fan blades at equal spacing.

Rotational speed is proportional to both suction and airflow. As the fan rotates, airflow can “spill” over the top of the blades causing turbulence and losses. In a dirty air situation where dust and dirt are also passing through the fan it is normal to leave the blades “open”. However in a clean air situation it is normal to add a cover to the fan, which prevents such losses. This cover or shroud is open at the inlet to the blades. Conventionally clean air fans are made from sheet aluminium. The back and shroud are pressed out in circular form from the sheet. Blades are also pressed out and subsequently shaped into curves which when fixed to the fan allow the air to be given energy as it is forced to pass over their surfaces during rotation. The curves are backward in relation to the direction of rotation. The curve is a complex shape to ensure energy is given to the airflow consistently as it passes outwards over the blades to the periphery. The closer the shape is to its mathematical derivative, the more efficiently energy is transferred. However in many cases blades are simple circular arcs to allow easy manufacture.

As the air passes from the inlet to the periphery its velocity is increasing; to match this, the blade height should be reducing towards the periphery to ensure smooth flow and the shroud should be formed to match this. For simplicity this often results in a conical form but as with the blade curve it is theoretically more complex than that for highest efficiency. In many cases this shaping is ignored and the fan is flat in form, leading to inefficiencies of flow.

In a dirty air system the fan is often a die-casting or a plastic moulding. This makes it ideal for giving all the shaping necessary to both blade curving and height variation. To a degree this will help offset the losses occurring at the top of the blades as previously mentioned.

When the airflow leaves the periphery of the fan it has a high rotational velocity and ideally should be contained within a volute, which increases in cross sectional area until it reaches an outlet point that is tangential to the radius. This is the most efficient way of guiding the airflow into the air ducts of the vacuum cleaner. The cross sectional areas of the volute and the outlet should match the airflow to ensure laminar flow with minimal losses. Broadly this form of fan cover is possible in a dirty air system and is normally employed.

In a clean air system it has been normal to utilise circular fan covers and to exhaust the airflow over the motor continually around the periphery or in some cases, static reverse form blades are utilised which "catch the air" to guide it towards the centre where it may then be exhausted over the motor. In effect the airflow is being "turned" ninety degrees to its original direction in a relatively short distance. This introduces significant losses and is one reason why such fan systems are so inefficient, as low as 20% at maximum suction power for the simplest fan designs. However by employing maximum shaping and ensuring high quality finished surfaces within the fan system it is possible to increase efficiency to more like 55%.

There is one type of clean air system that does not use the main airflow to cool the motor; this is known as a bypass system. In this case the airflow is exhausted from the fan cover around its periphery though shaped ducts, which tend to result in fewer losses. However these gains are partly offset by the need to have a supplementary fan to provide cooling for the motor. Such systems are normally used in vacuum cleaners that are associated with water pick up or filtration.

Finally it must be said that centrifugal fan systems work at peak efficiency only at a specific rotational speed as blade shapes and angles are designed to match that speed. The designer should be sure that this point coincides with maximum suction power.

1.1.8.1.2 Multi stage

Here two or more centrifugal fans are used in series, with two stages being most common. The same principles apply as to the previous section however since both fans are mounted on a single shaft, in line, the problems associated with airflow direction is now compounded as it has to be taken from the periphery of the first fan stage, via a system of static blades to the inlet of the second fan in the centre. In order to save space the distance between the two fans is usually little greater than the depth of the fans themselves. This effectively means that the airflow has to pass though two 180-degree turns in a very short space indeed. It is not surprising that the overall energy conversion efficiency of multi stage fan systems can be much lower than single stage systems. As with the single stage system losses can be reduced by ensuring the best shapes for blades, and fans. Surface finishes should be of the highest order. To offset these increased losses somewhat, a multistage system can operate at lower speeds which will reduce the losses caused by the friction of air passing over internal surfaces and can ensure that suction power is maintained over a more significant range. So whilst the fan system efficiency might be in the order of 35 - 40%, the vacuum cleaner will be able to cope with a wider variation of cleaning situations, as the airflow is maintained more consistently over a wider speed range at maximum suction power.

1.1.8.2 Axial Flow fan systems

Historically, axial flow systems have not been used in vacuum cleaners although experiments have been undertaken from time to time. The axial flow system has the advantage of potentially increased energy conversion efficiency due to the fact that the air is flowing through the fans without any change of direction. It would be possible to mount an axial flow fan system to a Universal motor – in line - and still allow the cooling airflow to flow over the motor; however the overall length of the motor fan system would increase when using an axial flow impeller or fan for maximum efficiency. It may be easier to mount to a more compact switched reluctance motor with the motor actually being in the centre of the impeller in order to save space. An impeller or fan of this type may also make it easier to be a moulding, which could ensure the optimum fan blade shapes being used

1.1.8.3 Positive displacement systems

Although there are many practical reasons why positive displacement systems are inappropriate for use in vacuum cleaners, including cost and noise levels, they do offer higher efficiencies. They are therefore included here solely as a reference point for what is technically potentially achievable.

Most positive displacement systems tend to have low internal losses. As long ago as the end of the 19^{th} century, there were large reciprocating pumps with efficiencies of 90%.

Today, there are two basic types of relevant positive displacement pumps: rotary and reciprocating. The reciprocating system is best suited to relatively high heads and small flows. It tends to cause troublesome pressure fluctuations. The rotary system suits lower heads and small flows, and can maintain a practically continuous flow with low pressure fluctuations against a wide range of heads. Typically positive displacement systems are used in compressors and they tend to relatively bulky

1.1.8.4 Rotary Type

1.1.8.4.1 a) Progressing Cavity

These pumps normally comprise of a rotating eccentric steel ‘screw’ running in a stator housing.

1.1.8.4.2 b) Sliding vane

These comprise a rotor running eccentrically in a circular casing. Vanes slide in and out of the rotor (or casing) maintaining contact with the casing (or rotor).

1.1.8.4.3 c) Peristaltic

These pump by squeezing air through a hose it is low cost but produces only low airflows.

1.1.8.4.4 d) Screw

These consist of axial helical screws meshing together. High suction and airflow is possible. However, the screws must be very accurately located without touching by timing gears. This makes the pump expensive.

1.1.8.4.5 e) Lobe

These could be viewed as gear pumps, usually with only two or three teeth meshing constantly together. However, unlike gear pumps, they are designed (using timing gears) to avoid the ‘teeth’ actually coming into contact. They run at low speed and are therefore relatively large for their duties.

1.1.8.5 Reciprocating type

1.1.8.5.1 a) Diaphragm

These consist of reciprocating flexible diaphragms with the flow controlled by inlet and outlet valves. They can be driven by a crank or by compressed air. Because of the diaphragms, suction is restricted and cost is high.

1.1.8.5.2 b) Plunger

These generate suction by a reciprocating plunger of constant diameter passing through a seal. They are designed for very high suction levels but with low airflow.

1.1.8.5.3 c) Piston

These generate suction by a reciprocating piston, the principle could be considered to be the reverse of a car engine. However, mean piston speeds are very much lower, probably less than 1 m/s. Thus the system is relatively large. High suction levels are possible but pulsations can be high. Airflow range is almost unlimited.

1.1.8.6 Motor/Fan Systems with intelligent controls

We have established that motor fan system work at peak efficiency at a specific speed. It is also a fact that microprocessor controls have been used for the past 25 years in order to modify the performance of the vacuum cleaner under certain conditions, clogging filters for example could lead to increased power to overcome the resistance of the clogging.

However by use of a microprocessor programmed to measure and react to suction power, it may well be possible to extend the peak suction power to a range rather than a single point and thus extend the most efficient range of operation for the vacuum cleaner. This may best be suited to electronically controlled brushless motors and may lead to reduced energy consumption. In many cases this will allow for a physically smaller motor/fan system, which will use less material and so will also have a lower eco-impact during the production phase.

1.1.9 Agitator (Brush Roll)

The first agitator consisted of a wooden cylinder with horsehair bristles inserted at regular intervals to form a brush roll. It was driven by a rubber belt from an extension to the main motor spindle. Originally brushing was the main function but it became apparent that vibration from the brushes acting on the carpet was also very beneficial. Eventually the cylinder became primarily made of steel and beater bars were added to augment the vibration. Modern agitators tend to be made primarily from plastics, such as polypropylene, and many use large contents of recycled materials. The bristles tend to be made from polyamide. Modern agitators tend to have significantly higher numbers of bristles and are usually arranged spirally so some bristles are always in contact with the surface during rotation. This has tended to reduce the vibration effect and more vigorous brushing has been substituted. This had, in turn, led to an increased potential for carpet wear.

Most effective agitation however, with least carpet wear, is still likely to be speed sensitive brushing and “beating” but with the negative that noise levels would be slightly higher.

The use of an agitator is the most cost effective way to remove soil from carpets and can lead to significantly lower suction power needs and hence lower input power also. Agitators are not only good at removing dust but they remove fibres, hairs and threads well also. Brushes need replacing regularly (every two years or so) for optimum cleaning performance.

1.1.10 Filtration

1.1.10.1 Barrier or Mechanical

1.1.10.1.1 Cloth

Cloth filters, usually cotton, have been used traditionally as filter media. For more than 50 years this was the main form of filtration, either large as cloth bags on uprights or smaller cloth bags inside canister cleaners. These bags were reusable but were quite messy to empty. The large cloth bags used on uprights were not designed for large dust carrying capacity but more to provide a large filter area with low air velocity to ensure no significant clogging or, since they were “outside”, the passing through or emitting of dust. They were designed to be emptied every week. Cloth bags were featured on uprights right up until the 1980s when they were largely superseded by hard containment mouldings with internal filter bags. Reusable cloth filter bags are still available for use with canister cleaners. They are relatively low cost in relation to their reusability and ability to be washed clean regularly to remove residual dust. They tend to be fairly leaky of dust especially with modern high suction power vacuum cleaners.

Felt filters were used for a long period, usually as secondary filters within a canister cleaner. They have not been used, as such, for the past 30 years and offer no advantages over alternative materials now available

1.1.10.1.2 Paper

The use of paper for a filter medium first appeared in the 1930s, however in the late 1940s became popular made into disposable paper bags fitted inside the cloth bags already in use. This overcame the messy emptying problem, although, due to costs, some users still wanted to empty and reuse the paper bags, even if occasionally they would burst due to excess wear!

Paper bags are still in regular use today, some have more than one layer of paper in order to absorb more dust and still reduce clogging. More and more have some form of self-closing device to further enhance the hygienic properties. They are relatively low cost to manufacture although are a lifetime on cost for the user who has to continue to buy replacements.

Paper is also used in a corrugated form in a cartridge as a media for secondary filtration. When used in this manner it is relatively low cost but is relatively fragile, hence is not easy to clean or durable and needs regular replacement.

All paper bags/filters are easy to recycle.

Paper filter technology is certainly able to allow the production of HEPA levels of filtration but filters must also fit properly into the vacuum cleaner to ensure no airflow bypasses them, as this would negate the effectiveness of the filter itself!

1.1.10.1.3 Treated Paper

Treating paper to give more strength is quite common. The treatment does not significantly affect the filtration properties. Filter cartridges made from treated paper are more durable, easier to clean and even wash carefully. It may, however lead to some problems concerning recyclability.

1.1.10.1.4 Manmade fibre (“fleece”)

Manmade fibres such as polypropylene are increasingly being used to make up filters and filter bags. They are made with such density as to aid high dust loading, which means little or no emissions and little clogging or reduction in airflow. They are relatively expensive are not generally reusable, however due to their filtration ability are made to ensure that bags can hold maximum quantities of dirt with some larger ones used in uprights tending to need replacing only twice per year. Potentially they can be recycled.

1.1.10.1.5 Moulded (sintered plastic)

The use of sintered plastics (polyethylene for example) has allowed porous mouldings to be made. The porosity can be controlled and using such materials hard, durable reusable dirt containers can be manufactured which also act as filters. They can be recycled however their filtering ability may not be as effective as other materials.

1.1.10.1.6 Water

If dirt-carrying airflow is passed through a water bath then the dirt can be “washed” out of the airflow thus using the water as a filter. Water is a cheap filter medium and it is completely recyclable. However, due to cavitation effects as the airflow passes through the water, some quantities of dust are held inside air bubbles so produced and can pass right through the filter process. It can also be messy, as the water has to be emptied after each use.

1.1.10.2 Non Barrier filtration

1.1.10.2.1 Cyclone systems

Cyclonic systems have been used for more than 75 years to separate particles from airflow. In 1948 a single cyclone system was even designed to remove different sizes of particles from the airflow via specific tapping off points within the cyclone. However truly effective cyclonic filtration was not seen on vacuum cleaners until 1981 when the first dual cyclone system was shown on UK television, subsequently to be sold in Japan. It was not for another 10 years that mass marketed cyclonic filtration vacuum cleaners appeared in Europe, initially in the UK.

The benefit of using a cyclone filter is to overcome the propensity for a barrier filter to become loaded with dust that may reduce the airflow and potentially reduce the cleaning performance. However the amount of suction power and airflow needed to create the cyclone' filtration operation is quite significant and can be equated to the amount of energy lost in a loaded filter. The initial systems were indeed energy hungry however their benefits were quickly picked up by users. Subsequent cyclone systems have tended to require less energy but need significant secondary filtration (barrier type), to complete the overall filtering operation. It is also not unknown for some cyclone systems to become blocked with certain types of dust or soil. However the net benefit is a completely reusable filter with little or no effect on cleaning performance as the receptacle fills with dirt. The benefit is reduced where more secondary filtration is required.

A cyclonic filtration system is normally used in a “bagless” container, which has to be emptied regularly. During emptying dust can be released in to the atmosphere and some question the potential hygiene issues. However it should be pointed out that many more bagless systems due not use cyclonic filtration to any degree, if at all, and these types may be considered even more unhygienic as the filters have the be cleaned every time of emptying also.

1.1.10.2.2 Electrostatic filtration

Charged plates mounted alongside the airflow path can be used to remove dust from that airflow. This type of system is used in some room air cleaners and has been proved to be reasonably effective. Historically there has been little interest shown in their use in vacuum cleaners.

1.1.11 Noise Control

Noise is an environmental pollutant and so the control of noise levels of vacuum cleaners should not be ignored. The most cost effective way to reduce noise levels is to use sound muffling and sound absorbing materials. This can add weight and some cost but can achieve reductions of more than 3 dBA when applied correctly. An alternative approach is to use the principle of noise cancelling. That is undertaken by generating a noise signal with exactly opposite frequency characteristics to those being produced normally by the vacuum cleaner. This is undertaking by sampling the noise frequency and applying the opposite signal from a frequency generator via a loudspeaker mounted on the vacuum cleaner. (Same principle as that used by noise cancelling headphones now popularly used on airplanes). This technology is expensive to apply however and adds to the complexity in a way that does not augment the cleaning performance.

1.1.12 Pneumatic principles

The design of nozzles and airways must comply with pneumatic principles for optimum benefits of suction power and airflow in particular to undertake work necessary in the task of removing soil from surfaces effectively and transporting that soil to a receptacle for storage. Airflow passes though and across a nozzle when it is in contact with the surface being cleaned. Whether or not an agitator is being used, it is vital that all shapes and cross sections comply with those principles. Similarly as the airflow passes through the connecting tubes, hoses and internal airways on the vacuum cleaner it should be laminar with no turbulence. All changes of direction should be accordingly designed.

1.1.13 Use of Materials

Vacuum cleaners have to look good as well as satisfying construction requirements. Whilst it is satisfactory to use low cost materials, such as polypropylene or polystyrene, the effects on appearance and longevity should not be ignored. The use of ABS, a good general purpose material can allow good looks and structural strength. The use of engineering plastics, such as polyamide or acetal may be kept to a minimum but must be used where appropriate. E.g. dirty air fan. Wheel bearings should be made with dissimilar materials. The use of modern moulding techniques, such as foaming and gas injection may be used to reduce material quantity without sacrificing strength. (weight saving also)

1.2 State of the art at component level (prototype, test and field trial level)

The study group is not aware of any developments in this category of products.

1.3 State of the art of best existing product technology outside the EU)

The study group is not aware of any developments in this category of products outside of the EU.

1.4 Summary

This section has discussed the many ways in which energy conversion efficiency of vacuum cleaners can be increased. Each of the design options has an economic cost, and in some cases may impact adversely on lifetime. The detailed decisions on what options are most appropriate for a particular vacuum cleaner will vary from design to design, and so in the LCC analysis in chapter 7 a generic relationship between efficiency and production cost is derived.

Beyond improvements to the actual design of the vacuum cleaner itself, the use of optimally designed centrifugal fan systems driven by a universal motor with possible microprocessor control is probably the most cost effective way to move forward at present. In combination with the use of an agitator fitted in a suitably designed nozzle producing appropriate vibration in addition to the brushing action the optimum cleaning performance on carpets may be achieved at the lowest suitable input power. Hard floors are generally easier to clean and agitation may be superfluous but good nozzle design is still important.

Emissions may best be controlled by use of well fitting High Efficiency Particulate Air (HEPA) filter media, either in conjunction with primary cyclonic filtration or with “fleece” material bags for more hygienic disposal.

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