Technical Recommendations and General Instructions for Vacuum Capacitors

This Service Bulletin is intended to supplement the data sheets with additional technical recommendations and general instructions which have to be considered with all applications of vacuum capacitors.

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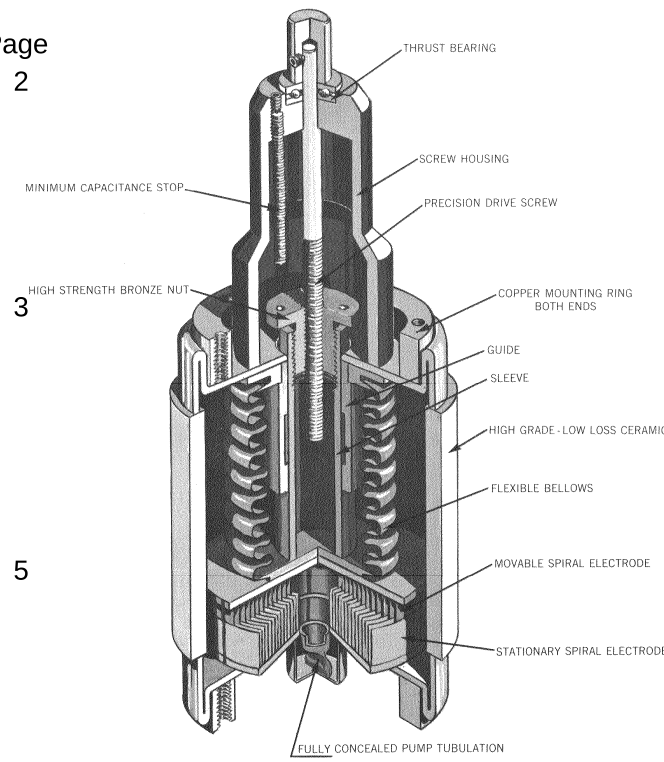


1. Choosing the Right Capacitor

1.1 Type Designation

COMET changed the Type-Designation System for capacitors at the beginning of 2004. Please consider Service Bulletin SB-55 for any further information.

1.2 Replacement of a Capacitor

With the COMET type designation, the specifications of the vacuum capacitors are well defined. It is important that the complete type code is specified when a capacitor is ordered. If a competitor's vacuum capacitor has to be replaced, please contact your local agent or COMET for clarification.

1.3 Capacitor Selection for a New Design/Application

Please note that all voltages are peak values and all currents are rms values!

If the capacitance and peak working voltage for the application is known, the theoretical current flowing through the capacitor can be calculated as follows:

$$I_{Arms} = \sqrt{2} \cdot \pi \cdot f \cdot C \cdot Upw$$

Upw = peak working voltage
F = frequency (Hz)
C = capacitance (pF)

Please also consider the idle or circulating current of the RF circuit. This current has to be added to the current determined above.

In order to select the right capacitor the following data have to be known:

– Capacitance range
– Peak test voltage, i.e. multiply the peak working voltage by 1.67
– The maximum current at the operating frequency

Example:

Capacitance	50 - 150 pF
Peak working voltage	8 kV
Frequency	13.56 MHz
Current at 50 pF	$I_{Arms} = \sqrt{2} \cdot \pi \cdot 13.56MHz \cdot 50\,pF \cdot 8kV = 24A$
Current at 150 pF	$I_{Arms} = \sqrt{2} \cdot \pi \cdot 13.56MHz \cdot 150\,pF \cdot 8kV = 72A$
Assumption:	current safety factor is 1.25
The max. current at 13.56 MHz is therefore	$1.25 \cdot 72$ A = 90 A_{rms}
The peak test voltage is	1,67 · 8 kV > 13.4 *kV* minimum

A suitable capacitor can be found on our website www.comet.ch.

The selected type is therefore: **CVUN-250AC/15-BAJA**

1.4 Lifetime Estimation of Variable Vacuum Capacitors

Although COMET capacitors are produced with best selected materials and fabrication processes there are limits based on movable parts which are necessary to adjust variable vacuum capacitors. Please consider Service Bulletin SB-56 which will give you in-depth information for lifetime estimation.

2. Electrical characteristics

2.1. Voltage ratings

Two voltage ratings are commonly used:

Peak test voltage: this is the maximum 50 / 60 Hz voltage that may be applied to a capacitor for one minute without causing internal or external breakdown. Vacuum capacitors up to 90 kV peak test voltage are available. Capacitors can be tested at this voltage to assess the general condition after shipment or prior to installation. For details refer to Service Bulletin SB-28.

Peak RF working voltage: this is the maximum peak RF voltage which can be applied continuously to a capacitor. Usually it corresponds to 60 % of the peak test voltage, thus providing an adequate safety factor.

When designing equipment for operation at high altitude, ambient barometric pressure must be considered, since external arcing across the ceramic envelope becomes more likely at reduced atmospheric pressure.

DC Operation

Combined DC plus RF, or DC blocking applications, present a particular problem for vacuum capacitors because of the field emission current.

COMET however has pioneered manufacturing processes that reduce field emission, as well as total leakage current of conventional capacitors for DC applications to less than 0.1 µA, a level which is significantly lower than what is generally accepted for regular RF applications. The standard leakage current is as follows:

Capacitor type	DC leakage current **at peak working voltage (Upw)**
Fixed vacuum capacitors	< 1 µA
Variable vacuum capacitors ≤ 15 kV	< 10 µA
Variable vacuum capacitors > 15 kV	< 1 µA

In praxis DC leakage current as low as 0.1 µA is frequently achieved.

To achieve excellent operating performance COMET recommends that the combined DC plus RF peak working voltage must not exceed the rated peak working voltage. As a good engineering practice the DC voltage should not exceed 25% or better yet 20% of peak test voltage.

2.2. Current Ratings

The specified RF current (see Figure 2) is the maximum uniformly distributed rms current a capacitor can handle under normal operating condition, i.e. at 25º C ambient temperature and pure convection cooling, if not otherwise specified.

For low frequencies the maximum current is given by the formula in chapter 1.3, and is limited by the peak working voltage of the capacitor. This maximum current is shown on the current diagrams (see Figure 2) as straight lines with a positive slope starting near the lower left corner. With rising frequency, one arrives at a point, where the maximum current is given by the maximum power, which can be dissipated and no longer by the peak working voltage.

On the current diagrams these points are the intersections of the lines with positive slope mentioned above with the lines with a slightly negative slope, which correspond to different types of cooling of the capacitor. Please note that the current limits given in the diagrams correspond to the capacitors of the highest voltage category. This is actually only of importance for the left part of the diagram, where the current limit depends on the maximum working voltage. Current derating diagrams (see Figure 6) must be observed for operation at elevated ambient temperature. The derating factor may depend somewhat on the type of cooling. For accurate derating factors equilibrium temperature measurements on the flange of the capacitor have to be carried out.

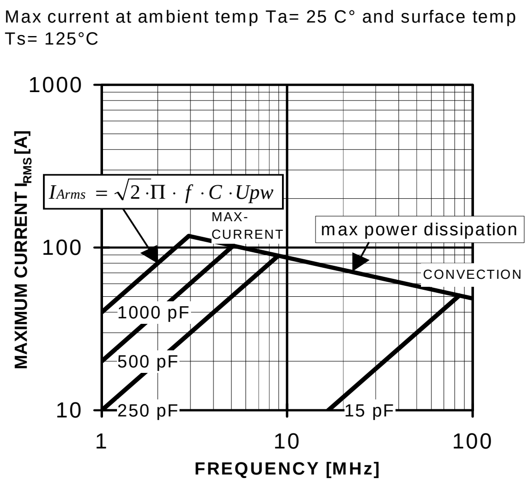


Fig. 2: Typical current vs. frequency and capacitance
Example: CVBA-500BC/8-BEA-L

2.3. Capacitance

Fixed capacitors with nominal capacitance greater than 50 pF shall be within a tolerance of ± 5 %. Nominal values of less than 50 pF have a tolerance of ± 10 %. The nominal capacitance range of variable capacitors is the guaranteed minimum range. Tracking accuracy of the capacitance slope is better than ± 10 % if the low capacitance end point of the linear range is used for reference.

Special design features permit COMET to manufacture capacitors with closer tolerances which are available on request.

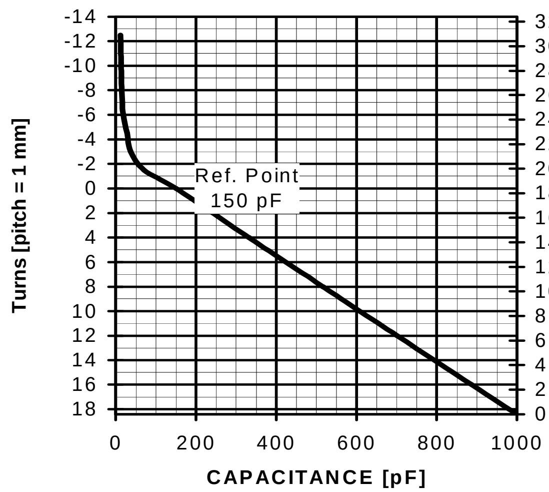


Fig. 3: Typical turns vs. capacity
Example: CVBA-500BC/5-BEA-L

Capacitance Control: Torque - Direct Pull Force

All variable capacitors are available with a drive-screw or a pull-rod to control the capacitance. Torque or pull force is specified for each capacitor.

All COMET capacitors have mechanical stops at either end of the capacitance range. Nevertheless it is recommended that the user provides his own end marks or stops, to prevent damage from powerful gear reduction drives.

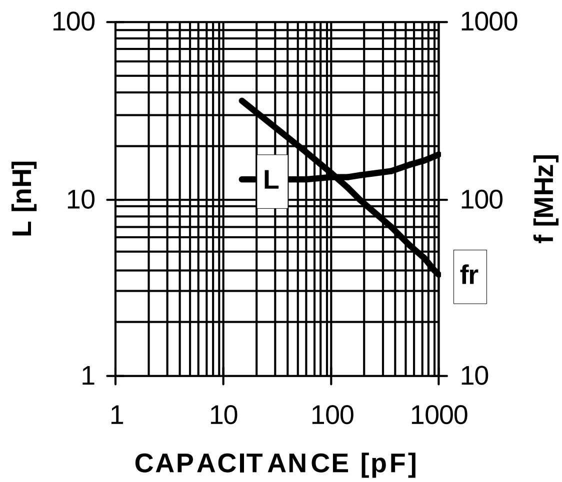
A frequent reason for the failure of vacuum capacitors is lack of adequate lubrication. The latter results in an increase of the torque until the drive coupling begins to slip, causing mismatch and possibly electrical overload.

Over the past years COMET has improved the lifetime of the drive mechanisms significantly. Extensive internal and external investigations and tests with different materials, surface treatment and lubricants have resulted in much higher lifetime well over 1 million cycles (see also Service Bulletin SB-47).

2.4. Self-Inductance, Self-Resonance Frequency and Q-Factor

The self-inductance of a vacuum capacitor depends mainly on its design and dimensions. It is extremely small and constant for fixed capacitors, ranging from approximately 2 to 10 nH, depending on the type. Variable capacitors have a larger internal inductance ranging from about 6 to 50 nH. This is due to the extended structure such as the bellows, connecting the movable electrode to its external mounting flange. Consequently the inductance of a variable capacitor changes with capacitance. The diagram below shows the dependence of the self-inductance vs. frequency, and self-resonance frequency vs. capacitance of a typical variable capacitor. The self-resonance of a vacuum capacitor is determined by its capacitance and internal inductance. Detailed data are on data sheets for most capacitors or are available on request.

Due to the extremely low losses that are typical for vacuum capacitors, the Q-factor is very high. The losses are caused by the RF resistance of the copper and, especially, the bellows. The losses and therefore the Q-factor are a function of the operating frequency. The Q-factor is generally lower for variable capacitors because of the additional series resistance imposed by the bellows. Typical values range from about 1.000 to well over 5.000.



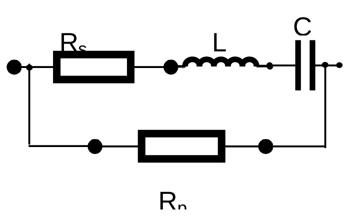
$$fr = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$$

$$Q = \frac{1}{2 \cdot \pi \cdot f \cdot C \cdot Rs} = \frac{1}{\tan \delta}$$

The parallel resistance *Rp* is negligible at normal operation frequency > 10 *kHz*

Fig. 4: Typical inductance and self-resonance of variable capacitor vs. capacitance
Example: CVBA-500BC/5-BEA-L

A more sophisticated model is based on the equivalent circuit shown in the Figure below. The frequency dependent behavior of the elements of this equivalent circuit is given on the second page of most of the data sheets.



R_s Series resistance
L Self inductance
C Capacitance
R_p Parallel resistance

R_p is negligible at frequencies between 10 kHz and fr

3. Cooling of Capacitors

3.1 Convection Cooling

Despite the very low losses of vacuum capacitors power dissipation in the bellows of variable capacitors and in the electrodes in general is of concern at elevated currents and high frequencies.

Bellow temperature is a relevant factor for the life expectancy of variable capacitors. Capacitors are frequently operated with convection cooling only. In general, COMET vacuum capacitors are designed to meet military specifications. They can be operated at temperatures up to, but not in excess of 125º C, measured anywhere on the capacitor surface, provided that the required RF current derating is considered. The maximum RF current rating for any COMET capacitor given in the data sheet is that current, which produces a maximum temperature of 125º C with an ambient temperature of 25º C. The temperature derating diagram gives the maximum permissible current for a given elevated ambient temperature in percent of the maximum current at 25º C ambient temperature. The derating depends some-what on the type of thermal contact which the capacitor has to the mounting structure. It should therefore be considered as a guideline only and is subject to verification by equilibrium temperature measurements on the flanges of the capacitor.

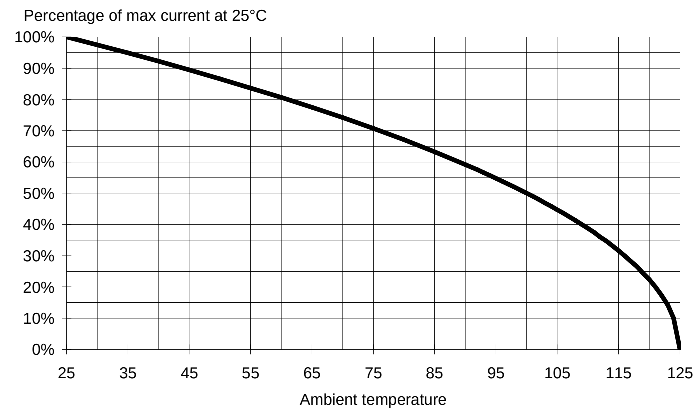


Fig.5: Derating RF current in percent of maximum permissible current at 25° C ambient temperature

It should be noted that the current derating curves produced by COMET are conservative since no conduction cooling is reflected in the data. In many cases this may result in lower values than shown by others.

3.2. Conduction Cooling

Every connection to a capacitor provides conduction cooling. The amount of the cooling (watts) depends on the thickness of the connecting straps and or the mounting itself. In fig. 6 is an example which shows the difference between true convection and convection plus conduction cooling. In each specific application the highest permissible temperature given on the individual data sheet has to be considered.

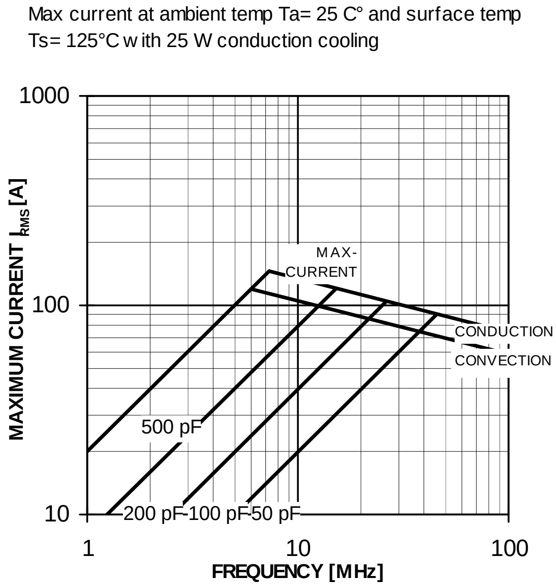


Fig 6: Typical current vs. frequency and capacitance
Example: CVPO-500BC/7.5-BECA

3.3 Forced Air Cooling

Additional cooling is recommended to achieve more favorable operating conditions or to increase current ratings. Substantially higher current ratings are permissible if forced air cooling is applied to the bellows. External cooling of the mounting flanges with forced air is also suitable for either kind of capacitor.

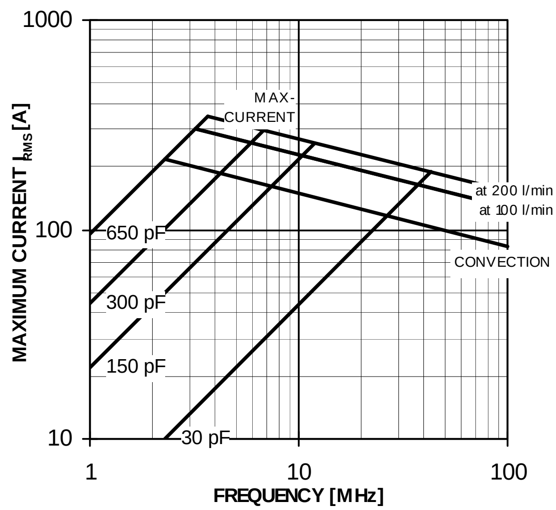


Fig 6: Typical current vs. Frequency and capacitance
Example: CVMA-650AA/55-ABB

Caution: Make sure that the cooling medium is non-corrosive and the inlet pressure does not exceed 1 bar. Also, the temperature derating diagram is to be considered for air-cooled types.

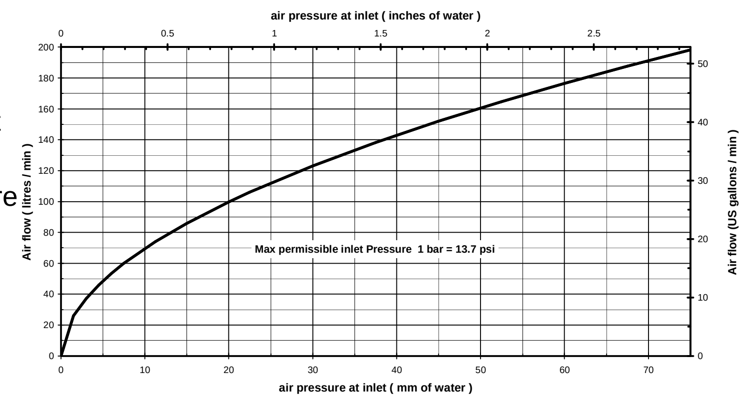


Fig. 7: Air flow vs. air pressure (typical)

3.3.1 Self-Lubricating System for Air-Cooled Capacitors

In air-cooled capacitors, air is forced to pass along the inside wall of the bellows where it can be heated considerably. The air then passes through the inside of the drive mechanism, thereby heating all the parts of the drive mechanism including the lubricant itself. The air eventually exits through holes centered around the red cap. The hot, dry air causes the lubricant to dry out faster. It also increases the viscosity of the lubricant, thereby causing it to be rubbed off.

Years ago, COMET developed the self-lubricating system, as shown in Service Bulletin SB-18, to prevent these disadvantages of air-cooled capacitors. It consists of a grease reservoir with a piston that is actuated whenever the drive screw is turned, thereby pushing the lubricant between the drive screw and drive nut. The COMET self-lubricating system may increase the life of an air-cooled capacitor by a factor of two to five! There is no change in the outline or in the installation procedure. The presence of a self-lubricating system in an air-cooled capacitor is indicated by adding an "P" to the type designation, for instance:

CVMA-650AA/55-AAB air-cooled, standard

CVMA-650AA/55-AAB-Pair-cooled, self-lubricated

Since the price difference between the two types is minor, we recommend to always use the self- lubricated version whenever it is available.

3.4 Water Cooling

Additional cooling is recommended to achieve more favorable operating conditions or to increase current ratings. Substantially higher current ratings are admissible if water cooling is applied to the bellows. Fixed and variable capacitors with water cooling of the base plate are available. External cooling of the mounting flanges with water is also suitable for either kind of capacitor.

CAUTION: Water flow requirements and absolute maximum inlet pressure, as specified for each capacitor type, shall not be exceeded to achieve long lasting high performance and expected life span. Inadequately dimensioned drainage pipe systems can cause excessive back pressure which in turn requires high inlet pressure that reduces bellows life significantly. Care should be taken that the cooling media water is non-corrosive.

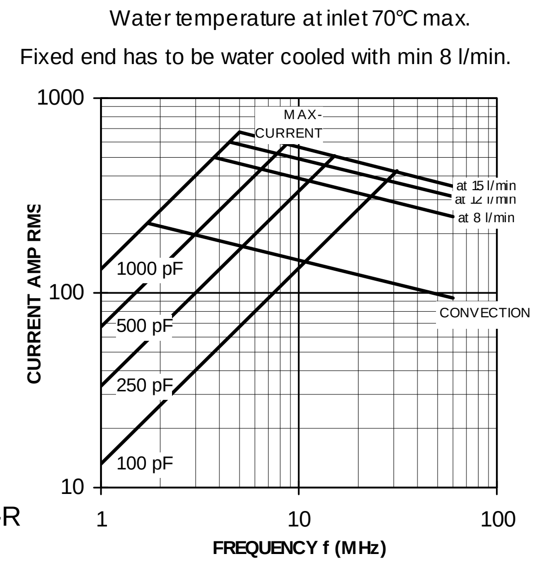


Fig. 8: Typical current vs. frequency and capacitance

Example: CVLA-1000BW/50-ZJP-R

3.4.1 Conventional Water Cooling

In the conventional water cooling design the water passes through the water chamber holes around the fixed guide shaft tabulation, the inside of the bellows and returns through the inside of the movable tubing (guide shaft) and the output side of the water chamber. This system operates well only in the vertical position. This is due to the fact that the water does not completely fill the convolutions of the bellows. This problem is enhanced when the bellows are compressed at the C-min. position. The air bubbles stay in the convolutions and are a cause of one intends to operate the capacitor in the horizontal position leading to premature failures. These capacitor types are usually cooled with a water flow of 4 to 15 l/minute. Additional restrictions for water cooling are imposed by the maximum admissible temperature rise between water inlet and outlet, and the maximum absolute inlet pressure, as specified in the data sheets, and/or by the maximum outlet temperature of 80 °C.

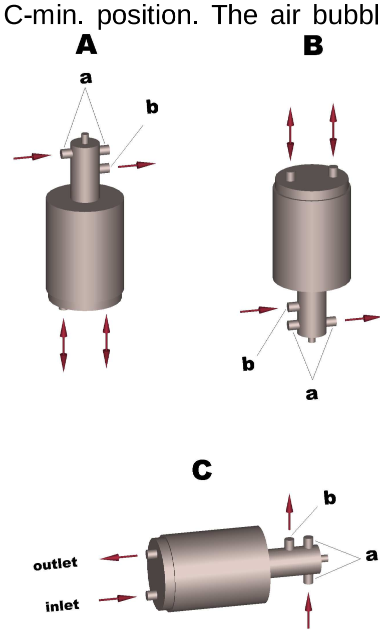


Fig. 9: Vacuum capacitors with water flow up to 15 l/minute

Fitting "a" is located on some water-cooled types on the same side as fitting "b". The formation of trapped bubbles along the bellows or in its immediate vicinity is avoided for mounting positions A and B and will then flow in direction as indicated. It is minimized in position C, such that trapped bubbles cannot cause fatal damage due to lack of cooling under normal operating conditions.

3.4.2 Turbulence Water Cooling

COMET developed the turbulence water cooling system, covered by the patent CH656740 A5 for the largest high power capacitors. The principle is based on the centrifugal effect imposed onto the water flow. This is done through especially designed injectors in the plate attached to the variable electrode. This way the water is forced against the bellows wall forcing any air bubbles towards the center where they are expelled with the outflowing drain water. It is important to note that this system functions either horizontally or vertically or any other position desired. The system assures that no air pockets can collect in the convolutions of the bellows which may adversely effect the cooling process.

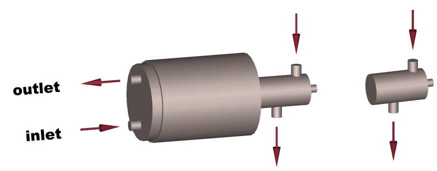


Fig. 10: Vacuum capacitors requiring 22 l/minute minimum, usually 25 l/minute

3.4.3 Water Cooling for Fixed Capacitors

Several fixed capacitors are available with special water cooling plates on both ends (sides) to increase the current ratings substantially.

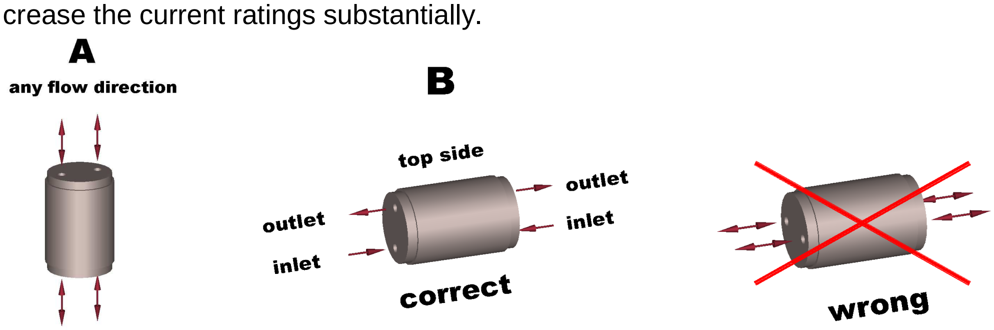


Fig. 11: Water connections for water-cooled fixed capacitors

3.4.4 Water Purity Requirements

Water-cooled vacuum capacitors require careful attention to maintenance of adequate coolant flow and purity to assure proper operation and long life of the components. Ordinary tap water will not meet these requirements. Distilled or deionised water should be used to fill such a cooling system. The water purity and flow protection

should be periodically checked to insure against excessive degradation. Water flow requirements and absolute maximum inlet pressure, as specified for each capacitor type, must be maintained at all times when the system is operating.

Water purity can be seriously degraded by contaminants from the various cooling system components. For example, free oxygen and carbon dioxide in the coolant will form copper oxide on the surfaces of the coolant courses, particularly on the inside of the water-cooled capacitors, thereby reducing the cooling efficiency. The formation of these oxides is greatly accelerated by the elevated temperatures within the system.

Electrolysis may also take place due to the presence of ions in the liquid and the electric potential across the coolant courses. Electrolysis may actually reduce the heat transfer to the liquid coolant. In extreme cases, heavy oxide deposits can actually plug up coolant passages and reduce flow. Either of these may result in premature failure of components, for instance a vacuum capacitor. Special cooling designs within a capacitor reduce these effects to a minimum but they are still present. A detailed specification for cooling water is available in Service Bulletin SB-26.

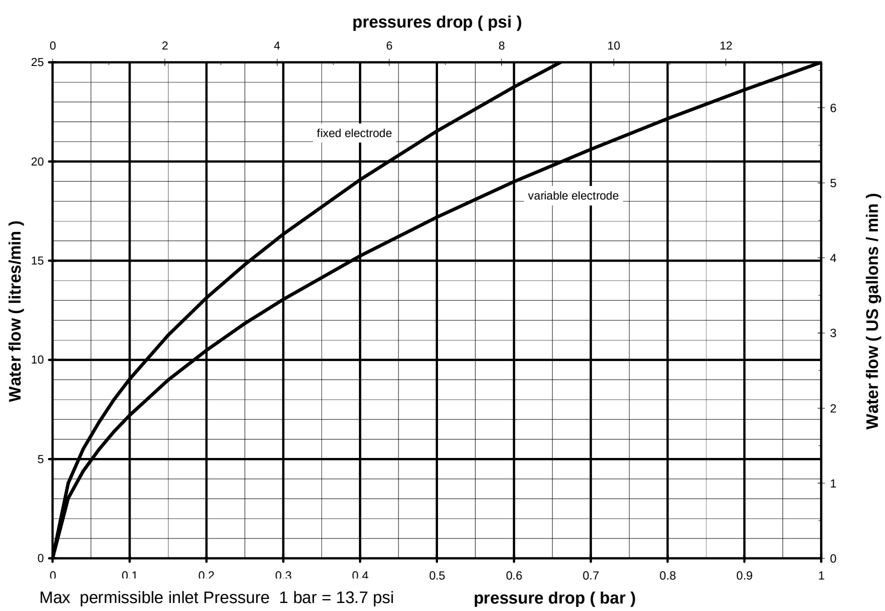


Fig. 12: Pressure drop across capacitor vs. water flow (typical)

3.4.5 Auxiliary Water Cooling for Convection-Cooled Vacuum Capacitors

A standard convection-cooled vacuum capacitor is cooled entirely by natural convection, i.e. only by the natural flow of air around the capacitor. Small capacitors, especially those used in industrial applications, are limited in the current carrying capability by the limited cooling obtained by convection cooling. The electrodes inside the capacitors are not yet taxed to the maximum limit possible. Some increase in the current limits is possible by conduction cooling. This, however, is relatively small.

A better improvement of the current range is possible when using the specially designed water cooling covers (see outline drawing for capacitor type CV1W-500EW). For smaller capacitors, the so-called minicons, this is a cost effective solution which can be readily mounted onto standard types. The overall dimensions are not

changed, only the height of the connecting rings is increased by a small amount (3 mm each).The largest increase in current can be experienced with capacitors with a relatively small size (diameter). As the size of the capacitor increases, the gain in current increase diminishes. This type of cooling is also advantageous in clean rooms where no forced air cooling of, for instance, matchboxes is permissible and relatively small dimensions are required. The current curve for the CV1W-500EW, see page 11, fig. 13, demonstrates the gain in performance which can be experienced.

Other types can be provided on request. See also Service Bulletin SB-7.

The cooling plates are mounted in the factory. This is necessary since the "red cap" is shorter than the standard one. Prior to shipment, the water course is checked against water leaks.

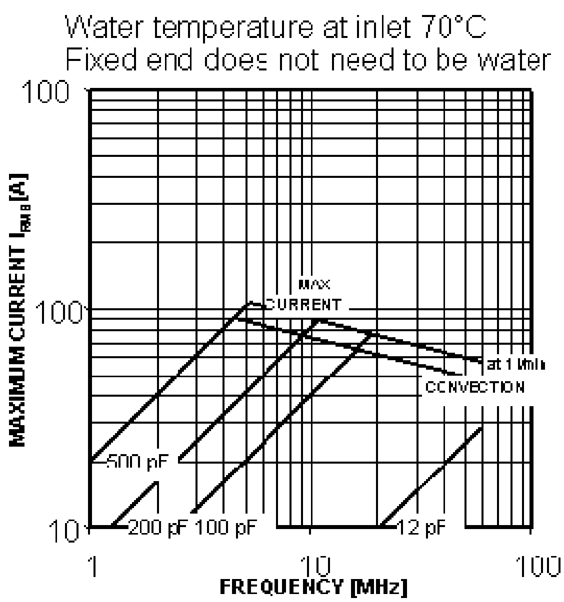


Fig. 13: Current curve CVMI-500AW/15-AAC-M

4. Operation and Maintenance

4.1 Handling

When installing or removing vacuum capacitors, extreme care must be taken to avoid damage to the body of the capacitor that can easily displace the electrodes. Whereas this was quite obvious with the old glass capacitors, it is less so with the modern ceramic types that can take higher mechanical and electrical/thermal loads. Although they look very rugged from the outside, one has to remember that due to the brazing process used to join ceramic and copper, the copper is in a soft, annealed condition and is therefore highly susceptible to mechanical deformation.

For this reason, any rough handling like machining of the flanges must be avoided. Use existing threads and holes for fixation. See also Service Bulletin SB-25.

4.2 Installation

Convection and forced air-cooled vacuum capacitors can be mounted in any position. Some precaution, however, is recommended for water-cooled types to avoid the formation of air pockets. Care should be taken to direct the water flow in accordance with the mounting position of the capacitor as indicated in section 3.4... This insures assure optimum cooling conditions.

For all capacitors we recommend that one side be mounted non-rigid to prevent excessive thermomechanical and external forces from acting on the capacitor. Most COMET capacitors are equipped at both ends with copper mounting rings. This is the standard mounting fixture referred to on the individual product data sheets. It is suggested that the mounting rings be used for all mechanical and electrical connections.

Most standard solid flanges contain 6 metric thread holes alternating with 6 inch-size thread holes. Special flanges and/or hole patterns and sizes are available upon request.

4.3 Recommendations for Storage of Vacuum Capacitors

Vacuum capacitors should be stored in a vertical position, in a clean, dry place. It is recommended to keep the capacitor in the hermetically closed plastic bag with silicagel during storage.

Periodic high voltage tests and, if necessary, high voltage processing (spot knocking) approximately every 4 - 6 months will maintain the voltage hold-off capability almost indefinitely.

If a water-cooled capacitor has been in service before, water should be removed from the inside of the bellows (i.e. water course), **using a vacuum pump.** See Service Bulletin SB-31.
Hold-off voltage tests of water-cooled capacitors should be made without filling the cooling system with water.

4.4 Shipping

For shipment, variable capacitors must be set to minimum capacitance. Whenever possible use original container.

4.5 Testing

Environmental Testing

Numerous environmental tests such as shock, vibration, thermal stability under RF-conditions, salt water spray, humidity and barometric pressure variation have been carried out on many capacitor types. Specific certified tests performed by independent laboratories can be arranged upon request.

In-house RF-testing can be done up to 30 kW and 30 MHz.

Electrical and Mechanical Quality Control

Every capacitor is subjected to extensive high voltage tests at 50 Hz prior to shipment. Variable capacitors are tested over the full capacitance range. Furthermore a DC test at 60 % of the peak test voltage is performed to determine the leakage current characteristics of the capacitor in both directions. The dimensional data and capacitance curve are carefully verified.

COMET recommends that the 50/60 Hz AC hold-off voltage test be carried out by the customer prior to installation.

Caution: Whenever DC-testing is performed, particular care should be taken. Capacitors charged with DC may hold their charge for days and are dangerous. Verify that they are properly discharged before handling.

Warning: The applied DC test voltage should not exceed 60 % of the rated peak test voltage. Reconditioning of capacitors should only be done with 50/60 Hz voltage.

4.6 Maintenance

Under normal operating conditions the capacitors do not need much maintenance. They should be freed from dust and dirt accumulation periodically. The unglazed ceramic envelope can easily be cleaned with a detergent and water.

Special grease or oil for periodic lubrication of lead screw can be provided.

5. Special Features and Services of COMET

5.1 Data Sheets, Curves, Various Technical Information

This Service Bulletin shows general technical information. Additional information and a quick reference list of all COMET capacitor types is given on the internet. For all these capacitors, outline drawings, C-curves, I-curves as well as inductance and in most cases self-resonance curves are shown together on the datasheet and could be downloaded. Please make sure that you are in the possession of the latest edition as they are subject to change without prior notice.

5.2 Analysis of Failed Vacuum Capacitors

COMET firmly believes that the ability to perform a prompt and thorough analysis of a failed unit constitutes an important tool both to improve our own products and to assist designers of RF equipment in improving their systems. A properly filled-in Service Report form will enable us to determine the cause of failure in most cases. A Service Report form is shipped with every capacitor leaving the factory.

In general this service is free of charge. However for special cases, e.g. if the capacitor returned is working properly, we reserve the right to charge an appropriate amount for analysis and report.

5.3 Service Bulletins

On special subjects, COMET is issuing Service Bulletins if and when appropriate that contain technical recommendations and technical information. Subjects covered so far

typically include maintenance, testing and disposal of vacuum capacitors, X-ray radiation and presentation of new products. These can be made available through your local representative, COMET or down loaded from our Homepage.

5.4 Special Versions of Vacuum Capacitors

Despite the high degree of standardization in the product line, COMET tries to accommodate special requirements of its customers as much as possible. It is through such efforts that product improvements like the integral flange or the double flat shaft end can be accomplished. Other "specials" such as spring loaded drive mechanisms for low torque actuation or capacitors designed for low inductance are available.

6. Conversion Table

Linear measures

inch	foot	yard	metric units	
1 in	0.083 ft	0.028 yd	2.54 cm	25.4 mm
12 in	**1** ft	0.333 yd	30.48 cm	304.8 mm
36 in	3 ft	**1** yd	91.44 cm	914.4 mm
0.394 in	0.033 ft	0.011 yd	**1** cm	10 mm

Square measures

square inch	square foot	square yard	metric units	
1 sq.in	0.007 sq.ft	---	6.452 cm²	645.16 mm²
144 sq.in	**1** sq.ft	0.111 sq.yd	929.03 cm²	---
1296 sq.in	9 sq.ft	**1** sq.yd	8360 cm²	---
0.155 sq.in	0.001 sq.ft	---	**1** cm²	100 mm²

Pressure

pound-force/sq.ft	pound-force/sq.in	metric units		
1 lbf/ft²	0.007 p.s.i	47.88 Pa		
144 lbf/ft²	**1** p.s.i	6.894 kPa	0.069 bar	
2089 lbf/ft²	14.5 p.s.i	100 kPa	**1** bar	1.02 at

Capacity measures

cubic inch	U.S. gallon	metric units	
1 cuin	0.0043 US gal	0.0164 liter	16.339 cm³
231 cuin	**1** US gal	3.785 liter	---
64 cuin	0.264 US gal	**1** liter	1000 cm³

Mass measures

ounce	pound	metric units	
1 oz	0.0625 lb	28.35 g	0.028 kg
16 oz	**1** lb	453.59 g	0.454 kg
35.27 oz	2.202 lb	---	**1** kg

Torque

inch ounce	inch pound	metric units		old units
1 ozin	0.063 lbin	0.007 Nm	0.7 Ncm	0.072 kgcm
16 ozin	**1** lbin	0.113 Nm	11.3 Ncm	1.153 kgcm
141.4 ozin	8.838 lbin	**1** Nm	100 Ncm	10.19 kgcm
13.87 ozin	0.867 lbin	0.098 Nm	9.8 Ncm	**1** kgcm

Temperature

Kelvin	Celsius	Fahrenheit
273	0º C	32º F
293	20º C	68º F
323	50º C	122º F
373	100º C	212º F
398	125º C	257º F

Temp. ºC = (Temp. º F - 32) · 5/9 / ∆ 1º F = ∆ 9/5º C