Compacting Ratio Calculations for Design of Power Cables

Version 2.0 – 01-Jun-2014

**A Microsoft Windows program from
Nano-Diamond America, Inc.**

Contents

Compacting Ratio Definition:

Compacting Ratio (CR) is defined for each individual compacting die, one die for each layer of conductors in the conductor body of a power cable. CR is the total cross-sectional area of all conductors entering a compacting die, divided by the cross-sectional area of the bore of the die.

A further figure called Differential Compacting Ratio will be defined later.

Introduction - The Reason for this Software:

Good design of power cables seeks minimum electrical resistance using only as much Copper or Aluminium as is actually necessary. Copper and Aluminium (especially Copper) are by far the most expensive components of a power cable.

The quality of the conductor body depends on many factors (process speed, angle of the cone of wires entering each compacting die, resistivity of the Copper or Aluminium, lubricant – if used, etc.), but CR is critical to performance. If CR is too high, not only is it likely that conductor material (especially Aluminium) will stick to the working surface of the die or dies (referred to as galling of Aluminium), but the individual conductors are likely to break due to excessive friction forces. These conditions create very costly production delays.

There is an even more costly effect which may occur. If a cable is designed with non-optimum CR values in one or more compacting dies, the amount of Copper or Aluminium required to achieve the desired electrical resistance will be more than necessary. Avoiding wastage of Copper and Aluminium is a primary design objective in most power cables.

When Nano-Dies® are used in compacting applications, the opportunity often exists to design power cables which require less Copper or Aluminium than when PCD dies or tungsten-carbide dies are used. The success of Nano-Dies in this application has re-awakened interest in Compacting Ratio as a key factor in cable design. Many cable manufacturers have become accustomed to compacting the conductor body very tightly with the object of reducing its overall diameter. In this way, it is possible to save some money on the cost of everything that goes outside of the conductor body (insulation, armoring etc). But what users of Nano-Dies have shown is that the achievable Copper or Aluminium savings when Nano-Dies are used are far greater than the savings which previously were achievable by any method when using PCD or tungsten-carbide dies. Using Nano-Dies, the optimum CR design is usually found with much lower CR values. Savings in excess of 2% of total Copper and Aluminium have been achieved by a significant number of cable manufacturers. By this, we mean total Copper or Aluminium usage has been reduced by more than 2% in many cases, compared with the amount of metal previously required when using PCD or tungsten-carbide compacting dies.

This software program to calculate the CR values has been designed to assist engineers and technicians involved with design of power cables to ensure that all the achievable savings are achieved in fact.

Installation:

Logon to your Windows PC or laptop with Administrator Privileges. The installation process will create a folder called **\Nano-Dies** on the **C:** drive of your computer and it is common for Administrator Privileges to be required by Windows for this type of operation.

If the software was received by e-mail in an attached file called **CompactInstall.zip**, the first step is to save and unzip the file and put all four files contained in the zip file into the same folder in the **C:** drive of your Windows PC or laptop. You can put the four files in any folder, so long as they are in the same folder.

The four files are called:
        InstallCRCalculations.bat   [Installation Batch File]
        Compact.exe   [Executable Program File]
        Current.dat   [Current Register Contents]
        CR Calculations User Guide.pdf [User Manual and Installation Instructions (this file)]
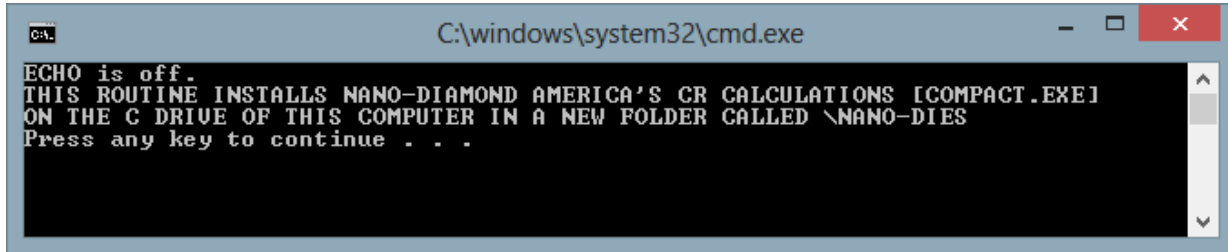
Note that the File Extensions (.bat, .exe, .dat and .pdf) will not be visible if Windows Explorer has been set to hide these. If you received the software on a CD-Rom or USB memory stick, it has already been unzipped for you and installation may proceed directly from the media on which the software was delivered. The four files listed above will be found in a Folder called **CompactInstall** on the CD-Rom or USB memory stick.

The next step is optional. Windows includes functions which are designed to protect you against viruses and malware which may be downloaded from the internet. Nano-Diamond America asserts absolutely that the software here included contains nothing harmful to your computer. You have to decide whether or not to believe this. If you are doubtful in any way, you are most welcome to contact Nano-Diamond America (admin@nano-die.com or call +1 (434) 906-2340) for further reassurance. If you are still doubtful, please do not install the software. Our purpose is to assist customers and prospective customers, not to worry them.

If you decide to proceed, you can temporarily disable the protection function, which Microsoft calls SmartScreen. In Windows 8, go to **Control Panel .. Action Center .. Change Windows SmartScreen Settings**. Then select **Turn off Windows SmartScreen**. You can turn it on again following installation. You can also leave SmartScreen running during installation of this software, but be prepared for some draconian warnings from Microsoft if you do this.
In Windows Explorer (called File Explorer in Windows 8), double-click the file **InstallCRCalculations.bat**. Or, if your Windows is setup to run everything with just a single mouse click, do that.
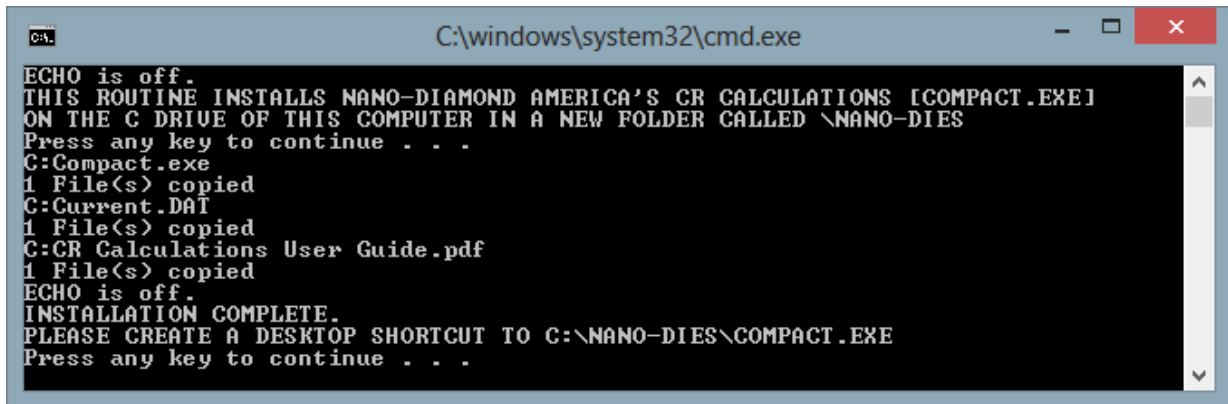
If Windows SmartScreen was left running, you may be stopped with a severe Windows warning at this point. If you click OK to this warning, the installation is cancelled. It is necessary to click more info .. and then click "Run Anyway" in order to proceed.

A black rectangular window called a Command Prompt appears, as shown immediately below:

Then press the spacebar or any active key and the installation completes as follows:

Press the spacebar again to close the Command Prompt window.

The next step is to create a shortcut to the program. Windows provides several ways to do this. You can pin the program to the Start Menu, or to the Task Bar, or you can simply create an icon on the Desktop to identify the program for ready access. We shall describe the Desktop Icon procedure. In Windows Explorer (File Explorer in Windows 8), right-click the program name **Compact.exe** (or just **Compact**) and hold the right mouse key down. Then drag the program icon to a free region of the Desktop and release the right button. A box appears with several options. Select **Create shortcut here**. Then, if desired, right-click the Desktop icon and select **Rename** and type in any desired name for the shortcut. The name **Compacting Ratio** is frequently used.

To run the program, double-click the icon (or just click it once if that is how your Windows is setup). If you did not disable Windows SmartScreen, you will receive another severe warning from Windows at this point. You need to repeat the same procedure as before in order to proceed (click more info .. and then click "Run Anyway"). Once you have run the program the first time, Windows will not trouble you again with the disruptive warning screen which, as already mentioned, is intended to keep your PC or laptop safe from all harm.

Installation is complete. If you disabled Windows SmartScreen, you can now re-enable it.

Using the program:

When the program is first run, it appears on the Desktop as shown here:

The program has two modes of operation. It is shown in the Calculator Mode. In this mode, results are automatically saved in memory registers when the program is closed and they are restored automatically when the program is run. When the calculation is saved, it automatically overwrites the previous calculation. The calculation is not given any particular name.

Considering only the lower section where the calculations are performed, the program scans for changed data every 0.4 seconds and then updates everything. Hence there is no need to click a button or hit Enter to make the calculation start. CR values are shown in **Bold Black** when they are less than or equal to 1.0 and in **Bold Red** when they are greater than 1.0. CR values less than 0.01 or greater than 2.0 are not displayed.

For the simple calculation shown on the left, it is necessary to enter the Bore Diameter of the compacting die, the Diameter of all of the individual conductors entering the die, and the total number of conductors entering the die. In this example, the First Die Considered might be the compacting die in the second layer, in the frequently used combination of 1+6+12 = 19 wires for the innermost part of the conductor body.

To assist in keeping track of the calculation results, the Total Cross-Sectional Area of Wires and the Cross-Sectional Area of the Bore are displayed at the bottom of the form. CR = 263.234 ÷ 271.424.

The simplest way to learn to use this program is to experiment with it. Make any desired changes to Bore Diameter, Dia. of Wires Entering Die and No. of Wires Entering Die and observe the effect on Compacting Ratio. The normal range of CR is from 0.8 to 0.99. In the process of experimenting, higher and lower CR values will almost certainly be encountered.

The numbers used in the examples here do not represent any particular cable design and there is no suggestion that any "optimum" result is indicated. Units of millimetres or inches are not shown, as either may be used for calculation, so long as units are not mixed.

Most often, the conductor body of a power cable requires more than one compacting die to process more than one layer of conductors. Consider an example using two compacting dies.

In the Configuration section click **Close** and **Discard Changes**. Then run the program again and click **2** in No. of Dies in Calculation. The Calculation expands as shown immediately below:

There are several things to note about this configuration:

No. of new Wires Entering Die:
In the right column of the above calculation (Next Larger Die), **18** has been entered as the number of new wires. The program automatically adds the Cross-Sectional Area of the 19 wires from the First Die to the Cross-Sectional Area of the 18 wires forming the new layer of the conductor body.

Compacting Ratio at the 2nd Die:
The Total X-Sect Area of Wires entering the 2nd Die is calculated as 512.613. The X-Sect Area of the Bore of the 2nd Die is calculated as 526.852.

Hence, the CR value at the 2nd Die is calculated as $512.613 \div 526.852 = 0.973$. All the wires entering the 2nd Die are taken into account, including wires from earlier stages of compaction.

Differential CR:

This figure is calculated as an indicator of whether the current layer is being compacted more tightly, less tightly or roughly the same amount as previous layers. Differential Compacting Ratio (DCR) is defined as

$$\frac{\text{(Cross Sectional Area of all New Wires in the Current Layer)}}{\text{(Bore X-Sect. Area Difference between Current Die and Previous Die).}}$$

In the example shown above, the Cross Sectional Area of the 18 New Wires in the 2nd layer is calculated as $18 \times (0.25 \times \pi \times 4.2^2) = 249.380$

Using the figures displayed for each die,
　　　Bore Cross Sectional Area Difference is 526.852 – 271.424 = 255.428

Hence, DCR = 249.380 ÷ 255.428 = 0.976 as shown.

Over-Compaction:

Over-Compaction is defined as CR > 1.0. In the example shown above, both CR values are < 1.0 and are displayed **Bold Black**. The conductor body is NOT Over-Compacted. But consider what would happen if the No. of Wires Entering the First Die was increased from **19** to **21**. The situation is shown immediately below:

The First Die is now Over-Compacted with CR = 1.072, displayed **Bold Red**. As displayed, there is now more Cross Sectional Area of metal entering the First Die (290.943) than the Cross Sectional Area of the Bore of the die (271.424).

The main point to note about the above Over-Compacted example is that the fundamental nature of the process has changed. The First Die is now DRAWING, not COMPACTING the conductor body. This is not a good thing for the conductor body or the compacting die. The optimum die profile required for drawing is generally different from the compacting profile. Die life and the efficiency of operation of the die are both reduced in this situation.

We must also change the way that the CR value is calculated for the 2nd Die. The Cross Sectional Area of metal coming out of the First Die cannot be more than the Cross Sectional Area of the First Die (271.424). So this is the figure used by the program, which is added to the Cross Sectional Area of the New Wires Entering the 2nd Die. This gives

Total X Sect. Area of Wires Entering 2nd Die = 271.424 + 249.380 (see above) = 520.803, as displayed.

Hence, at the 2nd Die, CR = 520.803 ÷ 526.852 = 0.989 as displayed.

Note that the DCR value is unchanged at 0.976. This is because neither the bore diameters nor the number of new wires entering the 2nd die have changed.
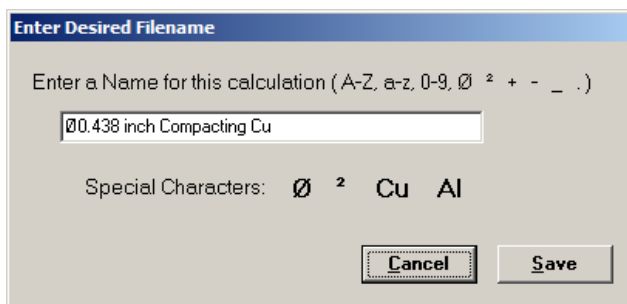
The program may be used in Calculator Mode in this way, to include up to five compacting dies.

File Mode - Open, Save Calc. and Save As Functions:

The program always opens in Calculator Mode. After using **Open** or **Save As**, the system enters File Mode until it is Closed. The **Open** and **Save As** functions are designed to help manage a number of different cable designs, details of which must be updated and stored. The **Open** function works almost exactly the same as in most popular Windows programs.

Save As:
To give a Calculator Mode result its own unique filename, click the **Save As** Button.
The Save As Dialog Box opens as shown immediately below:

The **Save As** template has been designed to assist in quickly creating a suitable filename for a CR calculaton. For example, if a Ø0.438 inch compacting die is featured in a calculation, the filename may be entered as shown. Or it may be desired to give a name such as "240 mm² Cu Cable". The special symbols Ø and ² may be inserted into a filename just by clicking the corresponding label shown. Most cables use are Copper or Aluminium, so "Cu" and "Al" labels have been included to simplify specifying to which metal the calculation refers.

When the Save button is clicked in the **Save As** template, the file is saved in the **\Nano-Dies** folder. The Calculation Caption becomes the new filename.

Save Calc:
Whether operating in Calculator Mode or File Mode, a calculation which has been modified may be saved at any time by clicking the **Save Calc.** button.

Open Saved Calculation:
Click the **Open Saved Calculation** button if desired to restore a previously saved calculation. An **Open** Dialog Box is displayed, very similar to the same function in many Windows programs. Select the desired saved filename from the list displayed and click the Open button in the Open Dialog.

Note that the **Open** Dialog Box may also be used to Rename or Delete an existing file. Just Right-Click the desired filename and select **Rename** or **Delete**.

Print Function and Image File Creation:

Click the **Print** button at any time and a **Title** template appears. The purpose of this template is to facilitate creation of an image file. If the calculation already has a unique Caption, this is used as the filename. If an un-named calculation is to be printed, a name may be give at this step. The Title step is optional. If used, the Title is entered exactly the same way as when using the **Save As** function, already described. The given Title is displayed as part of the image file or printed hard copy image. It is also <u>copied to the Clipboard</u>, to facilitate naming the image file the same as the Calculation name or title.

The first step is creation of a bitmap image of the current calculation in the **\Nano-Dies** folder in a file called **CRCalc.BMP**. Then the file is automatically opened using the **Windows Paint** program. A menu of options is available.

If **File .. Print** is selected, **Windows Paint** offers the user all the standard Windows printing functions and options. Assuming that a conventional printer is connected to the PC or laptop, a hardcopy of the calculation may be printed in the normal Windows printing procedure.

Paint also provides several useful ways to obtain a very efficient and compact image file of the calculation results. If **File ..** is selected, then if the mouse pointer is left sitting on the **Save As** menu item, the list of available options is as shown at the top of the next page:

Each of the available options represents a popular industry standard format in which the image of the calculation results may be saved (PNG, JPEG, BMP, GIF and Other Formats).

To select a file format, slide the mouse without clicking, until the pointer rests over the desired file format. Then click the mouse. A Windows "Save As" dialog box appears, allowing any desired file name and folder to be selected. We suggest placing the mouse in the File name box of the Windows "Save As" Dialog, then simply **Right-Click** and select Paste, to repeat the filename as set in the **Title** template in the previous step. However, any desired filename may be typed if desired (but some characters are illegal in Windows filenames).

Save as

PNG picture
Save a photo or drawing with high quality and use it on your computer or on the web.

JPEG picture
Save a photo with good quality and use it on your computer, in email, or on the web.

BMP picture
Save any kind of picture with high quality and use it on your computer.

GIF picture
Save a simple drawing with lower quality and use it in email or on the web.

Other formats
Open the Save As dialog box to select from all possible file types.

Any of the popular formats are useful, but the PNG format uses the least disk space and provides an excellent image quality, which Microsoft describes as "lossless". All of the supported formats may be attached to e-mails, uploaded or downloaded from the internet, or imported into word processing programs such as Microsoft Word.

Advanced:
You may prefer to use a program other than **Windows Paint** to open the bitmap image file. In that case, **Right-Click** the **Print** button. A small template appears, enabling you to choose either **Windows Paint** or **Your Own Choice of Default Program** to use to open the bitmap image file. If you select your own choice of program, an additional step is required to run the program. Use Windows Explorer (File Explorer in Windows 8) to navigate to the **C:\Nano-Dies** folder, then **Right-Click** the filename **CRCalc.BMP** (or just **CRCalc**) and select the program you want to use, from the list provided by Windows. Check the box labeled **Use this app for all Bitmap files**.

After the desired program has been selected to open the bitmap image file, a Desktop Shortcut to the bitmap image file **CRCalc.BMP** may be created in exactly the same way as the program shortcut was created during installation of the software. Then, to open the bitmap image file using which ever program has been selected for bitmap files, just double-click or click the shortcut icon.

Convenience Functions:

ClearAll:
The purpose of the **ClearAll** button is to clear the present calculation, to make way for a new calculation. All calculation fields are cleared, including those which may not be visible if the No. of Dies in the Calculation is set to 1, 2, 3 or 4.

When the program is closed, either by pressing the **Esc** key or by closing the Calculation Form using the **X** button in the top right corner, or by clicking the **Close** Button, the current calculation is saved. It will be re-displayed when the program is run next time. But if **Close** is clicked immediately following **Clear All**, the calculation is NOT saved. Hence, if **Clear All** is clicked in error, it is possible to click **Close** immediately and then re-open the program, to recover the calculation to the state it was in before any unsaved changes were made.

Clear Right:
Right-click the **Clear All** button to clear only those calculation fields which are not visible, to the right of the last column of the calculation.

Duplicate Diameter:
Frequently, the Dia. of Wires Entering the Dies is the same for all layers of the cable. If you right-click any box labelled "Dia. of Wires" or "Dia. of New Wires", the value in that box is copied to all the boxes to the right of that box, to save you having to re-type the same number.

Size:
The program always starts at the normal size on screen. If the Up arrow is clicked, the program image on screen is made 25% larger, to improve readability. The original size of the program image on screen may be restored by clicking the Down arrow.

Display User Guide (this document):
Press function key F2 from the top or bottom section of the main form at any time if desired to display this User Guide on screen. (Some computer setups require fn+F2 to be pressed together).

General DesignGuidelines:

The most important objective of the design of the conductor body is to ensure that there is enough Copper or Aluminium to make certain that the cable will pass the electrical D.C. resistance test is passed. The conductor body is the most expensive part of a power cable. Hence, the second objective is to ensure that Copper or Aluminium usage is limited to what is actually necessary.

Many factors are involved. To list a few:
    Number of layers
    Number of conductors in each layer
    Diameter of conductors in each layer
    Bore Diameter of Compacting Die at each layer
    The type and quality of Compacting Dies used
    Resistivity of the Copper or Aluminium
    Angle of the cone of wires entering each die
    Speed and condition of the compacting machine
    Lubricant (if used)

Obviously, only the first four of these factors are taken into account by this program. But one common factor runs through the entire process – the less damage that is done to the conductor body during compaction, the lower will be the final electrical resistance. The Compacting Ratio results provide an immediate guide to the amount of damage that will be done at each stage of compaction. Some damage is caused by compression forces, but the majority is caused at high values of Compacting Ratio, due to elongation of the cable. The larger the force required to pull

the cable through the compacting dies, the greater is the damage to the conductors. Friction in compacting dies is the biggest factor.

Nano-Dies do less damage to the conductor body than tungsten-carbide dies or PCD dies, due to the superior surface quality of Nano-Dies. This creates less friction, hence fewer dislocations are created in the Copper or Aluminium at microscopic level, hence the conductor body is likely to have measurably lower electrical resistance when Nano-Dies are used.

Regardless of the type of dies in use, the design can cause less damage or more damage to the conductors, depending on how the Compacting Ratio values are set. The following guidelines on setting CR values are not given as absolute truths, but they have been found to be helpful by a number of users of Nano-Dies, who have achieved significantly better results using Nano-Dies than they were previously able to achieve using PCD dies or tungsten-carbide dies, whether over-compacted, or not.

1. Maintain a good degree of uniformity in CR values between layers
2. CR values may rise gradually, from the innermost layer to the outermost layer
3. DCR values should not be significantly different from the CR values
4. For Copper, target $0.95 < CR < 0.98$. For Aluminium, $0.90 < CR < 0.95$

About Version 2.0:

- The Caption of the top section of the main form (previously named "Configuration"), is now named "CR Calculations V2.0" [page 4].

- The **Save As** function has been enhanced to permit easy use of special characters in the filename, such as Ø and ². Filenames are checked for illegal characters before a Windows error message is generated [page 7].

- The **Print** function has been enhanced in two ways [page 8]:

(a) If a previously saved calculation is being printed in the form of an image file, the Title of that calculation is carried through to the filename of the image file, including any special characters included in the Title.
(b) If a Calculator Mode calculation (no Title) is being printed, a Title template is displayed, enabling a Print Title to be entered in exactly the same way as for the **Save As** function. Additionally, the Print Title is copied to the clipboard, enabling the Print Title to be used as the filename if an Image File is being created, rather than a hard copy being printed. For example, if saving a calculation image as a .PNG file, simply Paste the clipboard contents into the Windows File name box in order to create the same Windows filename as the Print Title.

- Access to the User Guide (this document) is provided via Function Key F2 [page 10].