Wind Generator Tower Splice Bolts: The Problems in North America

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Introduction

Wind generators, designed and built for many years in Europe, are now being constructed and manufactured in North America. Because the engineering for them has been based on European standards, the bolts used to assemble them have usually been designed as metric. In a wind generator, there are all the various bolts in the nacelle, the bolts connecting the hub to the generator, the bolts connecting the blades to the hub, and the bolts used to splice the tower sections together in the field. They all are important and critical.

But this discussion will concentrate only on the tower splice bolts. In Europe these are big bolts, typically M36 at least, more frequently M42 and M48 diameter, and occasionally M56 and M64 (!!). Lengths of the M42/48 vary from 330 to 380 mm, and grade 10.9 strength is typical.

North American Tower Splice Bolts – What Bolts to Use?

Obtaining metric bolts in North American is a real problem because our bolts are almost always imperial, not metric. The three or four large bolt producers in North America (Nucor, Infasco, St. Louis, and Unytite), although they can make metric structural bolts, effectively don't. To get them interested you have to give them an order for tens of thousands of bolts, all the same length, for delivery at the same time, and even then you probably have to wait a couple of months. And tooling for metric bolts larger than M30 might not exist.

Metric bolts can be brought in from offshore manufacturers (like Cooper and Turner in UK), with fairly long deliveries and stock replenishment problems, but so far North American bolt distributors have not brought in much stock of these metric bolts. There are a couple of 'custom' bolt importers/manufacturers in North America, like Chicago Bolt and Dyson, and as the wind business grows perhaps these sources will prove to be adequate, but for them to supply (say) half a million tower splice bolts in one year could be difficult. And that's what it's going to take when all the wind farms are being built in North America.

Are the bolts in tower splices what, in North America, we call structural bolts? Is the tower a structure, or is it part of a machine? A typical generator is pictured here, and might have the following dimensions and weights: hub height 70 m, rotor diameter 90 m, weight of one blade 6.6 tonne, weight of rotor 40 tonne, weight of generator unit (nacelle) 68 tonne, steel weight of supporting tower 108 tonne.

(see figure 1 here – Typical Generator)

I don't think there's any doubt – the tower is structural steel, and therefore the bolting in the tower splices must come under the Research Council on Structural Connections. This is the North American body that writes the design and installation specifications which govern all bolted structural steel connections. Why not wind towers too?

North American Tower Splice Bolts – How to Tighten Them?

Contrary to European specifications and experience, the RCSC Specification prohibits tightening by means of predetermined tabular torque values. The RCSC advises that preloading bolts by means of a torqueing procedure such as might be implicit in the European bolted connection design code (VDI 2230) will lead to large variations in installed preload, and therefore increased risk of bolt failures.   The practice of stamping installation torque values on the bolt head is, in North America, not only not recommended, it is prohibited, dangerous, misleading and will cause in-service problems.

And, it appears that the wind industry is experiencing bolting problems. Anecdotal evidence from several wind generator manufacturers and maintenance crews tell us that pretty well ALL of them are having bolting problems. But it's understandably not easy to get a full description of the problems from the field crews and from the QA people. In a prominent trade magazine in March 2008, the largest wind generator company in the world, Vestas, admitted that two failures resulted from **"…insufficiently tightened bolts…"** If you look through the internet (for instance, http://www.windaction.org/news) you will see hundreds of situations that are called failures, many of these in tower splices, and many that are conceivably influenced by the load capacity of the bolted splices.

These tower splices are a steel designers' nightmare. The design loads are to a large extent predictable, but each bolt is loaded in service by what we call very high prying loads as the wind pushes on the tower. Furthermore, the service loads are non-conservative: that is, if one bolt is unable to resist the applied prying load, that load is transferred to the adjacent bolt, which may cause more distress, etc. And also, there is a certain dynamic component to the service loads which has to be resisted by the splice bolts.

The only way to ensure that the bolts are going to survive in service, presuming that the number of bolts is designed correctly (there's no saving a splice design that has too few bolts in it), is to get them uniformly tightened (read tensioned) to a very high percentage of their strength. That is, as every bolted joint designer will tell you, is the best insurance against loosening because the correctly tensioned bolts will not see very much change in tension as the external service loads come on and off. If the bolts are tensioned correctly and only experience a small percentage change in tension as external loads occur, the fatigue life of the bolts is practically infinite. And the opposite is true. If they are not tensioned correctly, they will experience a large percentage change in tension, cyclically, and their residual clamping force will gradually shake down to nothing. Once the clamping force has dropped to nothing, every cycle of external load will change the force in the bolt by a very high percentage, and the fatigue life of the bolt will limit its serviceability.

That's why the installation tightening (again, read tensioning) procedure is all-important. Tightening the tower splice bolts, in European practice, is done using torque values. In North America, tightening must be done by a torqueing procedure called "calibrated wrench", by part-turn, or by using direct tension indicators (DTIs).

Note that in Canada (part of North America of course), ANY torqueing procedure used to install structural bolts is not allowed, but in the US a "calibrated wrench" torqueing procedure is allowed, *but only under certain strictly controlled conditions.*

Calibrated Wrench – This is NOT a specified torque value. It is an involved procedure whereby, every day, for every batch of bolts, a sample of three bolt sets from every batch of bolts must be brought up to 5 percent over the intended installation tension in a calibrated Skidmore device, the torque required to get to this tension averaged, and then in the tower this torque is to be used, systematically, on all the bolts. The next day, and for a different batch of bolts, another set of three tests must be done. And, perhaps most importantly, the condition of the bolts tested daily in the Skidmore must match the condition of the bolts in the splice joint. If the splice bolts have been stuffed and not completely tightened for, say, a few days or weeks, the test bolts must also be similarly exposed and used for the calibration tests.

Part Turn – Take three bolt sets from each batch, exposed similarly to the splice bolts as described above, and in a Skidmore make the proscribed part turn (1/3rd, ½, 2/3rds) depending on bolt L/d ratio, and ensure that the tension on the Skidmore is at least 5 percent over the intended value. Then systematically put that same rotation on all the splice bolts. Since the RCSC has not published a metric specification, and since the thread pitch of metric bolts is in general different from imperial bolts, the amount of rotation to be used here is problematical, and would have to be determined from thorough research. This is why in tower splices, no one to my knowledge uses a part turn tightening procedure.

DTIs – Up to and including M36 grade 10.9, these are compressible washers made to ASTM F959 or EN14399 Part 7, and are used by the millions in all kinds of structural steel connections, all over the world. For bolt diameters larger than M36, they are also made, and do work well. DTIs are basically steel washers with impressed bumps on one side, made so that the tension imparted into the bolt as the bumps compress will be equal to or greater than what is required by the design. Again, their performance on site must be shown to be correct by means of putting three samples on bolt sets in a calibrated Skidmore, and ensuring that there is a “useable gap” or reproducible squirt at 5 percent over the intended bolt tension. These are now manufactured in diameters and strength grades to suit all splice bolts from M36 right up to M64 diameter, from 510 kN to 1680 kN.

(see figure 2 here – Large Diameter Metric DTIs)

North American Tower Splice Bolts – Comparison of Bolt Specifications

In the following table, I chose one bolt size (M36 x 300, galvanized) and gathered together the relevant comparative data for each. This is the data which might be needed to help choose which grade of bolt and nut to specify and then install in the tower splices. To be sure, availability in North America, right now, is problematical for all of them.

Metric Bolt/Nut Comparison for Wind Generator Tower Splice Bolts

Example: M36 x 300 Galvanized Bolt, With overtapped Nut, Stress Area 817 mm*2

	Bolt and Nut Specification					
Characteristic	DIN 931/934 Bolt PC 10.9 Nut PC 10	EN 14399-3 (HR) PC 10.9	EN 14399-4 (HV) (DIN 6914/15)	ASTM A325M/ A563M	ASTM A490M/ A563M	ISO 4014/ 4033 Bolt PC 10.9 Nut PC 12
Thd Pitch mm	4	4	4	4	4	4
Thd Length mm	97	97	52	63	63	97
Nut Depth mm	27.4-29	29.4-31	27.7-29	35-36.6	35-36.6	33.1-34.7
Nut O/O Flats mm	53.8-55	58.8-60	58.8-60	58.8-60	58.8-60	53.8-55
Nut Hardness Rc	Rc 36 Max	Rc 26-36	Rc 26-36	Rc 26-38	Rc 26-38	Rc 26-36
Nom Bolt Tensile Strength kN	850	850	850	678	850	850
Proof Load Nut kN	808	947.7	866	952	952	980.4
Expected Failure Mode	Thread Stripping	Bolt Fracture	Thread Stripping	Bolt Fracture	Bolt Fracture	Bolt Fracture?
Cost Ratio	90	90	90	80	100	120
Availability?	sp order	sp order	sp order	sp order	sp order	impossible
Nut Dilation Factor	0.86	0.95	0.95	0.95	0.95	0.86

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Here is a quick commentary of each assembly:

DIN 931/934 -- the shallowest of all the nuts listed, and being the narrowest, nuts likely to dilate at extreme load shedding thread engagement and coming loose. Not a structural assembly.

EN 14399 -- Either the British (HR) or the German (HV) type, both excellent bolts with relatively deep and wide nuts, intended for preloaded applications. Our experience with the HV style, despite the possibility of failure by thread stripping, when made by thread rolling AFTER heat treating, is excellent. We can recommend either of these assemblies.

ASTM A325M/A563M -- Good strong bolt and very deep nut, but not likely to be used much in this application because the bolt itself simply does not have enough overall load capacity.

ASTM A490M/A563M -- Excellent bolt and very deep nut, but when galvanized should be done carefully watching the upper hardness bound to avoid hydrogen embrittlement, but can be (say) dacromet coated instead. When coated correctly, this bolt is a winner for preloading, and when installed over 70% of minimum UTS, will provide superior performance.

ISO 4014/4033 -- Not too bad an assembly, although the nut is narrow like the DIN 934, but when the property class 12 nut is chosen because of overtapping to suit galvanizing, the assembly will, probably, pull the bolt right up to fracture, which is good. Unfortunately, you just can't get the pc 12 nut anywhere, period. So don't go with this assembly.

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