IBP1190_12

COKE DRUMS INSPECTION AND EVALUATION USING STRESS AND STRAIN ANALYSIS TECHNIQUES

Marcio I Haraguchi[1], Mahmod Samman[2], Ediberto B. Tinoco[3] , Fábio C. Marangone[4] , Hezio R. Silva[5] , Gustavo C. Barcelos[6]

IBP1190_12
COKE DRUMS INSPECTION AND EVALUATION USING STRESS AND STRAIN ANALYSIS TECHNIQUES

Resumo

Reatores de coque deformam devido a uma complexa combinação de esforços mecânicos e térmicos cíclicos. Essas deformações chamadas de “bulges” (bojos) que tem caráter progressivo representam o principal problema de manutenção relacionado a este equipamento. Apesar das falhas potencias geralmente não apresentarem um grande risco às pessoas, eventuais correções para a manutenção da confiabilidade destes equipamentos podem requerer grandes intervenções que impactam bastante a capacidade operacional da unidade. Desta forma, o estado, a progressão e a criticidade dos bulges devem ser acompanhados rotineiramente. Reatores de coque podem ser inspecionados durante as paradas de unidade com o uso de escâner laser tridimensional e inspeção visual remota que resultam numa detalhada avaliação dimensional e visual de sua superfície interna. Um típico projeto tem os seguintes objetivos: inspecionar o equipamento para gerar recomendações de manutenção e inspeção, comparação com resultados anteriores e gerar dados base. Até o momento, a análise estrutural do vaso tem sido tradicionalmente feita pela analise de Fatores de Concentração de Tensões (SFC) através do método de elementos finitos que, no entanto, tem sérias limitações teóricas e práticas. Em função disto foi desenvolvida a técnica de PSI (Plastic Strain Index) que representa o estado da arte para a análise de reatores de coque, mostrando excelente correlação com falhas, este método é baseado em critérios das normas API 579/ ASME FFS.

Abstract

Coke drums deform due to a complex combination of mechanical and thermal cyclic stresses. Bulges have progressive behavior and represent the main maintenance problem related to these drums. Bulge failure typically result in through-wall cracks, leaks, and sometimes fires. Such failures generally do not represent a great risk to personnel. Repairs needed to maintain reliability of these vessels might require extensive interruption to operation which in turn considerably impacts the profitability of the unit. Therefore the condition, progression and severity of these bulges should be closely monitored. Coke drums can be inspected during turnaround with 3D Laser Scanning and Remote Visual Inspection (RVI) tools, resulting in a detailed dimensional and visual evaluation of the internal surface. A typical project has some goals: inspect the equipment to generate maintenance or inspection recommendations, comparison with previous results and baseline data. Until recently, coke drum structural analysis has been traditionally performed analyzing Stress Concentration Factors (SCF) thought Finite Element Analysis methods; however this technique has some serious technical and practical limitations. To avoid these shortcomings, the new strain analysis technique PSI (Plastic Strain Index) was developed. This method which is based on API 579/ ASME FFS standard failure limit represents the state of the art of coke drum bulging severity assessment has an excellent correlation with failure history. .

[1] Bacharel em engenharia mecânica – TRICOM TECNOLOGIA E SERV DE MAN IND LTDA.
[2] Doutor em engenharia mecânica – HOUSTON ENGINEERING SOLUTIONS
[3] Mestre em engenharia civil – PETROBRAS S.A.
[4] Mestre em engenharia mecânica – PETROBRAS S.A.
[5] Mestre em engenharia metalúrgica – PETROBRAS S.A.
[6] Bacharel em engenharia mecânica – PETROBRAS S.A.

1. Introduction:

During their cycle, coke drums are subjected to internal pressure, weight and coke loading, but it is during the quench phase that the most intense stress appears from the difficult to obtain a homogeneous cooling of the vessel due to the thermal isolating properties of the coke and the random channels inside the column. Temperature differences create high thermal stresses that would lead to bulges on the walls. With growing nature, bulges should be monitored and analyzed closely as they are focus of cracks initiation and might compromise the life time of the equipment. In this context Tricom developed inspection tools and offered in Brazil a new strain-based analysis method for evaluating coke drums. This paper describes the inspection tools compares the advantages and disadvantages of stress and strain analysis techniques.

2. Laser Scanning and Remote Visual Inspection (RVI)

The internal surface of the coke drum can be scanned during unit turnaround with the aid of last generation laser scanner where data gathered at 0.0018 degrees on each axis, resolution of 0,1 mm and accuracy of 1mm in 50 m. For statistical reasons at least two cloud points are recorded per each drum. Additionally, for a precise targeting and matching of the several cloud points, each one should contain all internal surface of the drum. In consequence there is no need to interpolate data to generate the internal shape of the drum. This process takes 1 to 2 hours total job time per drum in the field. In the post processing stage all data is registered in a one single raw cloud point. An example is show in Figure 1.

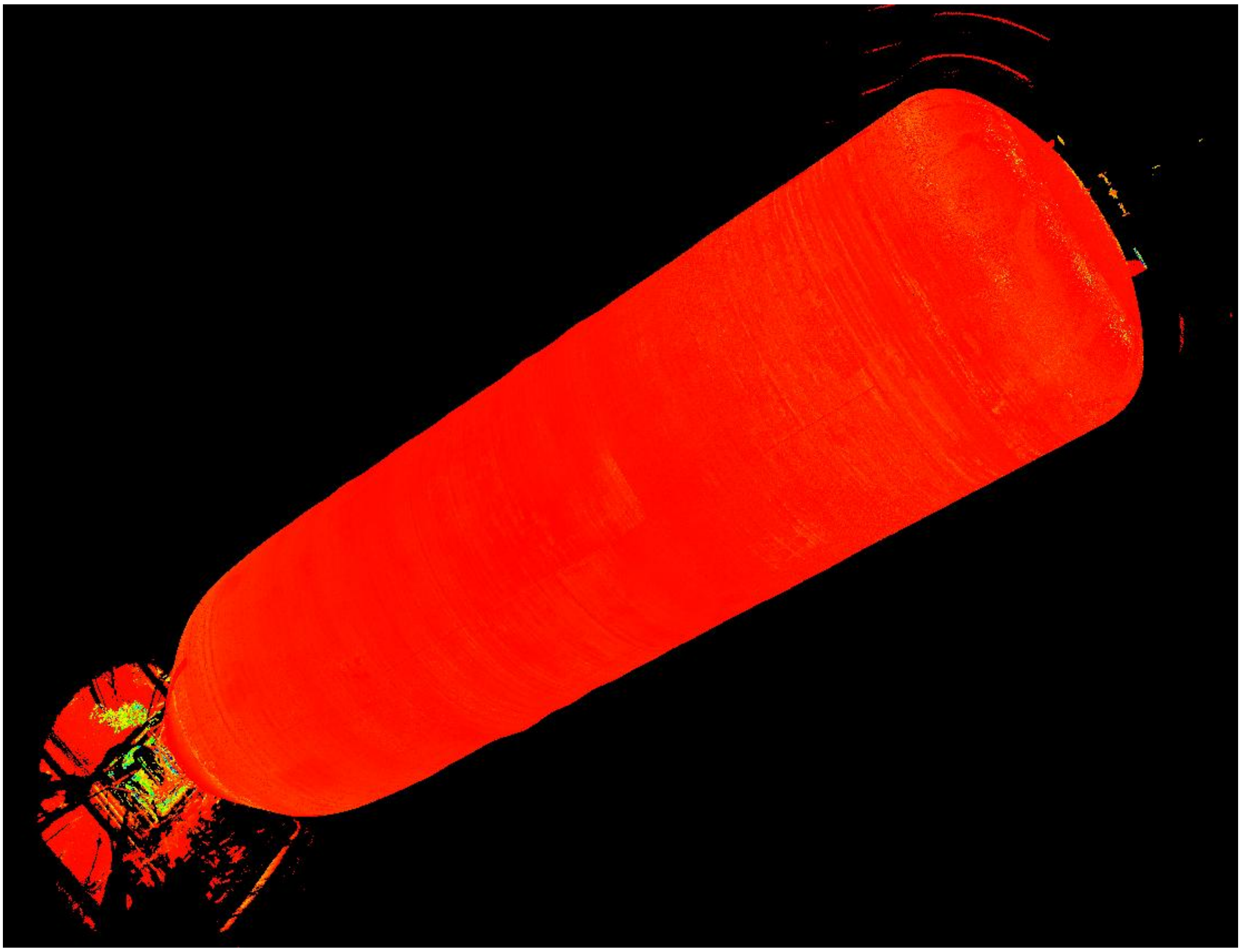

Figure 1 – Tridimensional view of the 3D laser scanning raw cloud point.

The data is then cleaned from interferences and cropped to contain only the cylindrical part of the drum (Figure 2) resulting on an average base cloud point with 100 millions of measurement points.

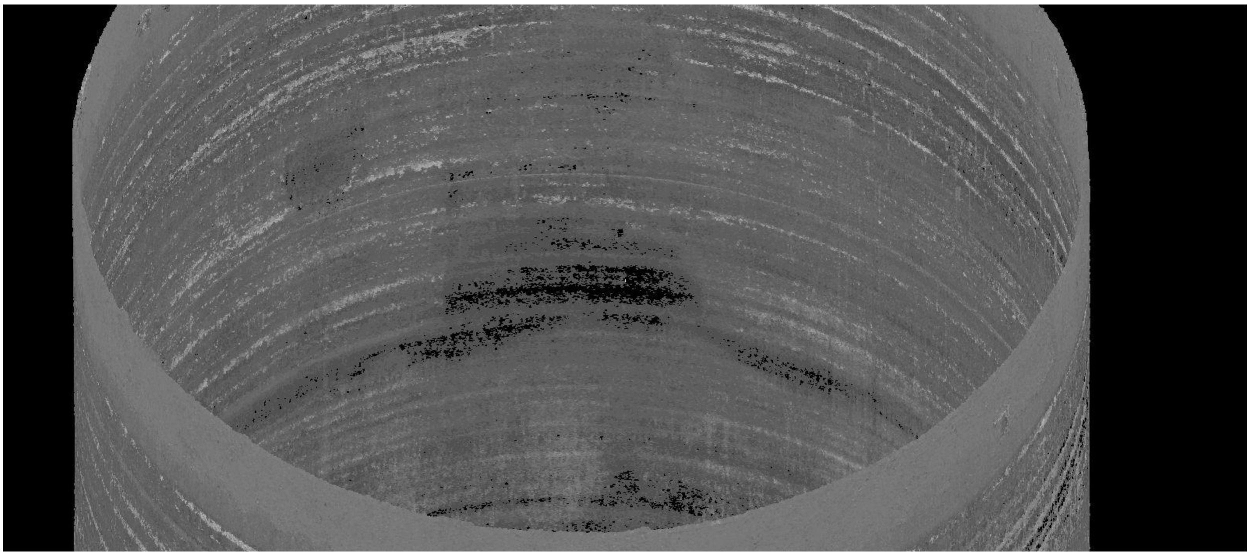

Figure 2 – Three-dimensional view after cleaning and cropping the raw cloud point.

The huge amount of data generated guarantee a good statistical base for the next step where the data is filtered, treated, analyzed and reduced to generate a basic data matrix (Figure 3) that will be used on the structural analysis. This process eliminates spurious data points or noise. This matrix usually corresponds to 1 line per inch on the elevation and 1 row per degree on the azimuth, every cell representing around 50 measurement points.

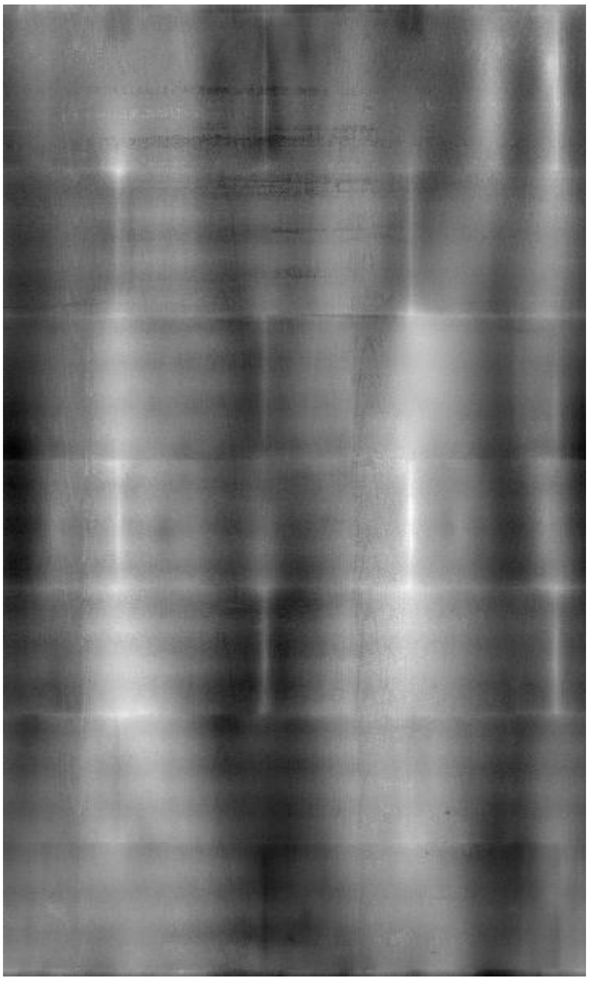

Figure 3 – grayscale visualization of the base data matrix.

The base data matrix would also generate a contour plot, or radius map (Figure 4). The resulting image represents the geometry of the internal surface, permits calculating the radius variation and the general shape of the drum. The good statistical base of the data allows us to visualize even small details on internal surface like weld lines and thin coke patches.

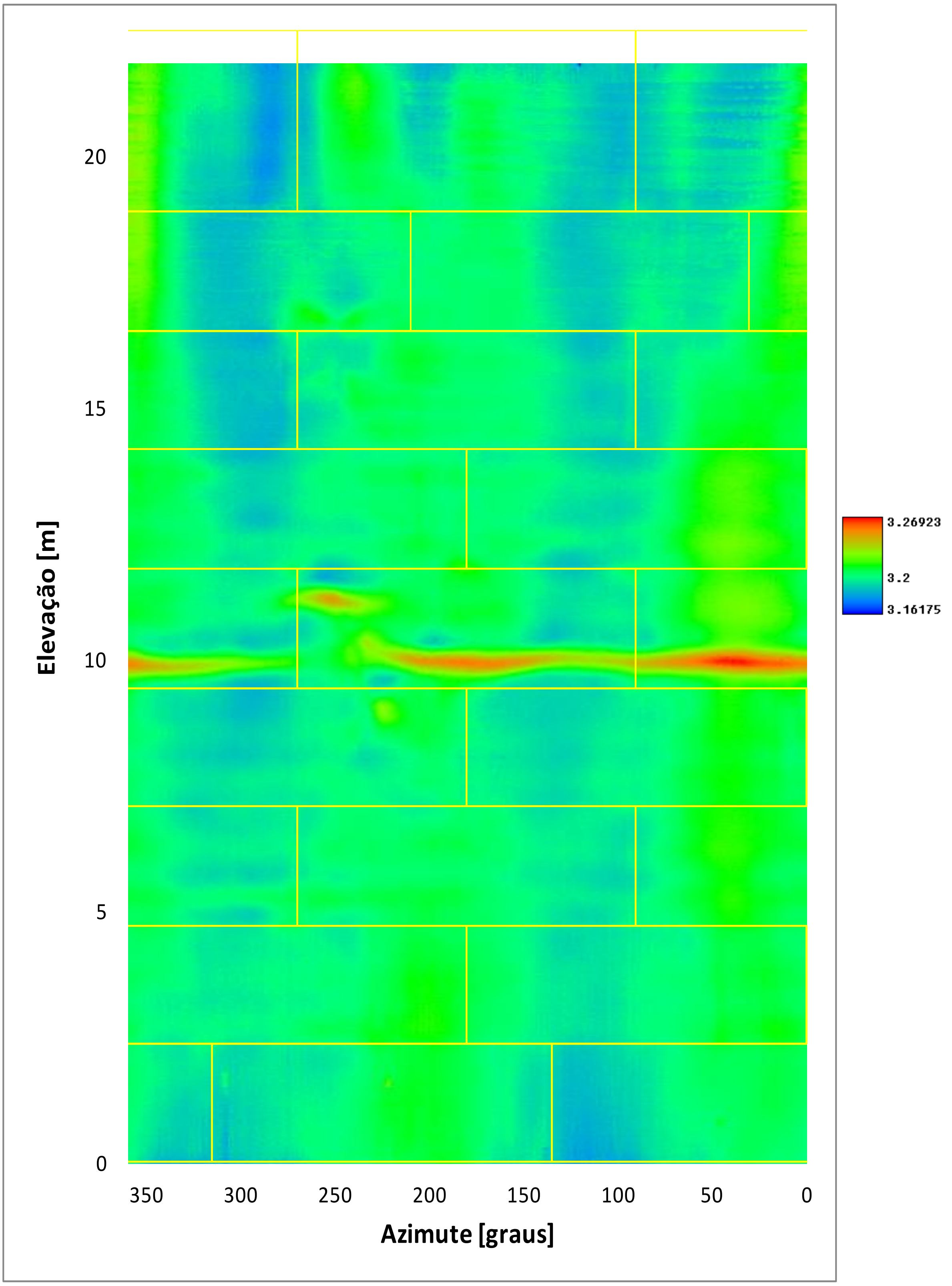

Figure 4 – Contour plot or radius mapping.

In parallel, a Remote Visual Inspection (RVI) service photographically registers the internal surface of the drum without entering the vessel. Every high resolution photo covers usually a 50 cm per 100 cm area. The RVI process takes 2 to 3 hours total job time per drum. An example of high resolution photo is shown on Figure 5.

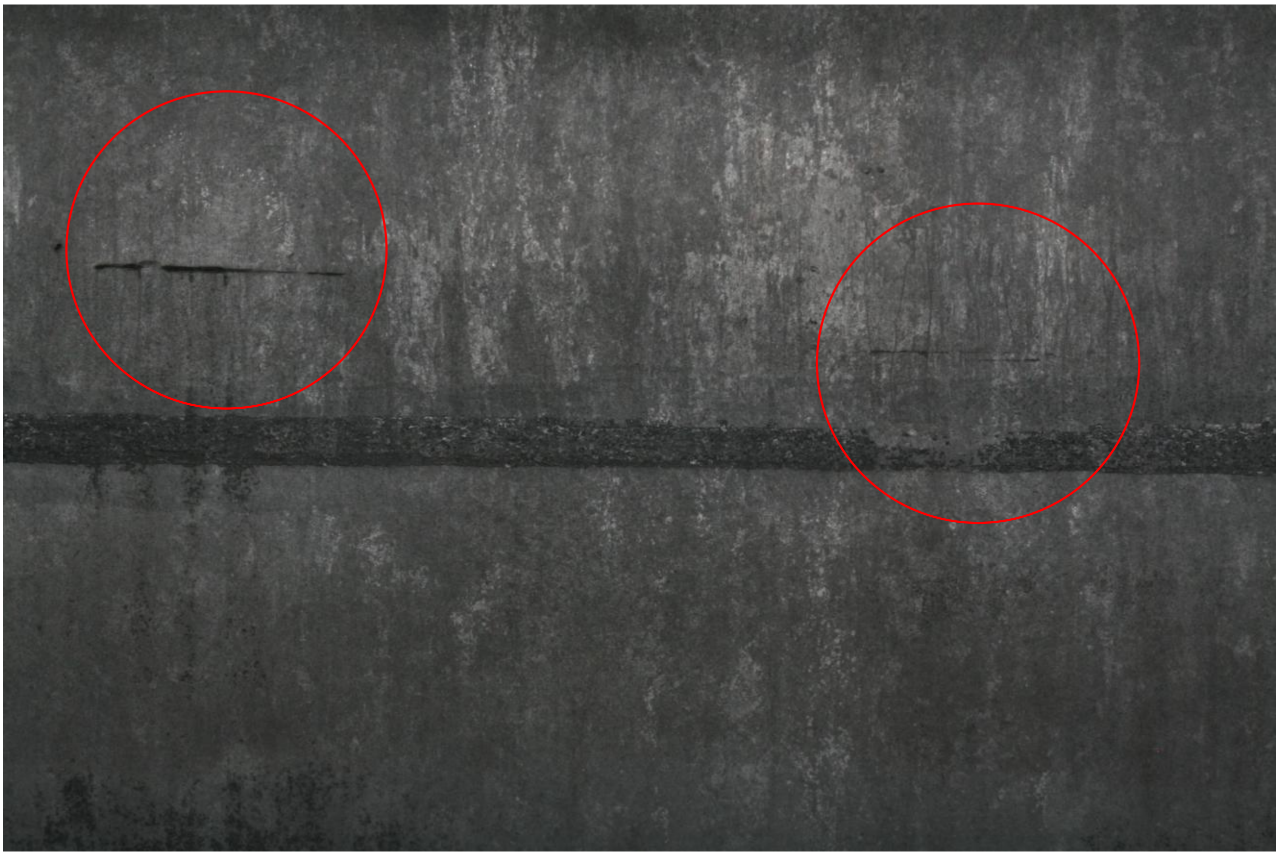

Figure 5 – High resolution photo of a coke drum internal wall with visible cracks.

3. SCF and PSI Analysis

The Stress Concentration Factor (SCF) was developed in the 1990s for assessing the severity of bulges in coke drums. This first-generation technique was based on the assumption that bulging severity is proportional to stresses that develop in bulged drums under internal pressure loading. Given two primary stress components in a shell (axial and hoop), two sides of the wall surface (inside and outside), and two ends to the range of stress concentration factors (SCF) (positive and negative), there are eight values that summarize the result of every analysis. Usually, axial stresses are viewed as more representative of bulging severity than hoop stresses. For interpretation, some users suggested that a stress concentration factor of six be used as a limit. Other more conservative users used a limit of five instead.

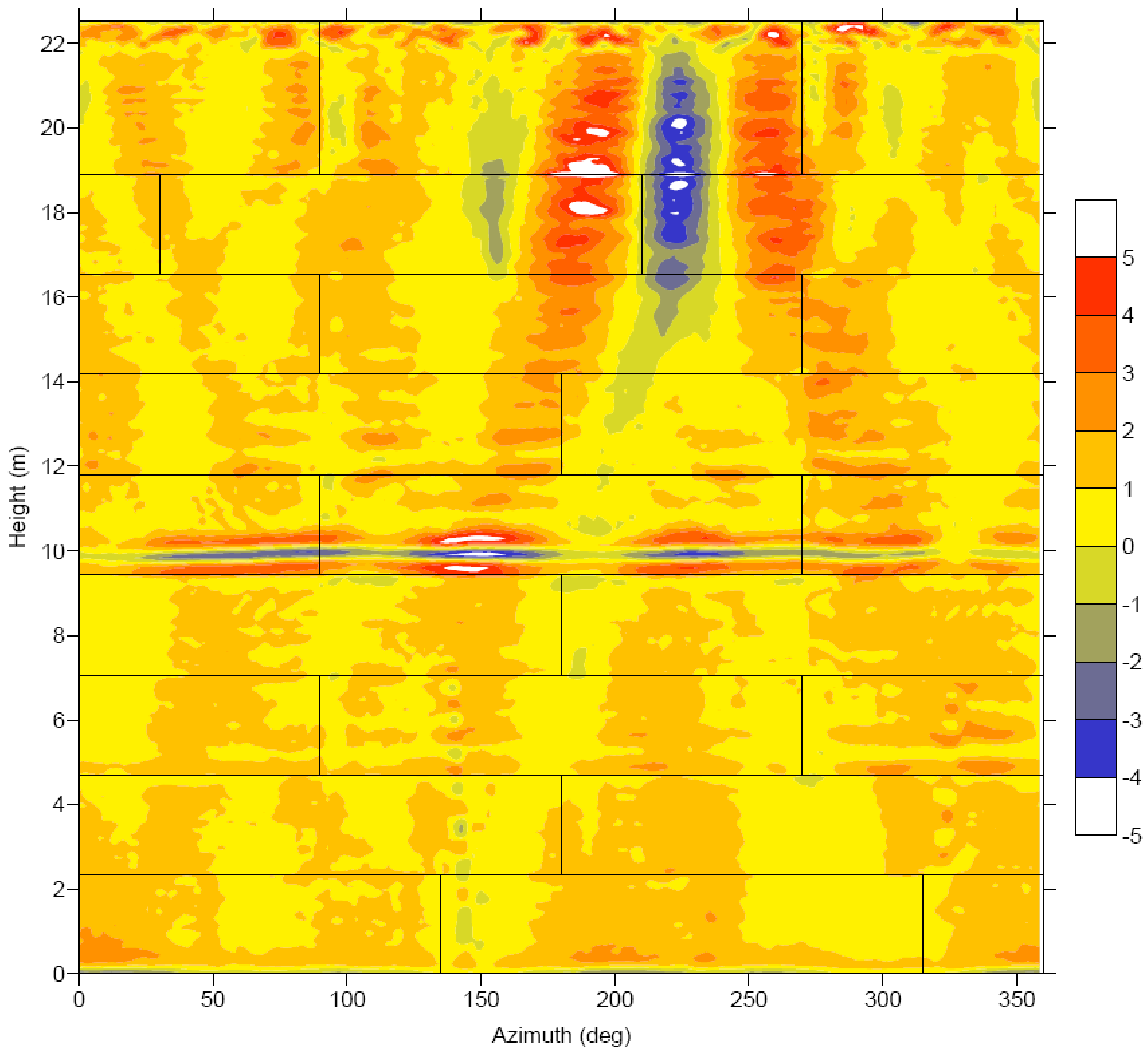

Figure 6 – Outside axial SCF (note the high ovalization error in the top two courses of drum).

The Plastic Strain Index (PSI) is a methodology for assessing the severity of bulging in pressure vessels such as coke drums. The technique is designed to help owners make decisions regarding life-cycle management of their drums and help inspectors plan their work and optimize the allocation of their resources. The strain-based methodology helps to identify and rank the areas that are most susceptible to local failure using strain limits provided by API 579/ ASME FFS Standard. The result of the analysis is a map of the PSI which is a percentage of the lower un-factored strain limit per the 2000 and 2007 editions of the Standard. A margin of 2.5 is used to define the design threshold. The ranking of severity between this design threshold and un-factored strain limit is defined using a three-tier system that divides severity into “Concern”, “Danger”, and “Failure” levels. Positive values of PSI refer to failure initiation on the inside of the drum and negative values refer to initiation on the outside of the drum.

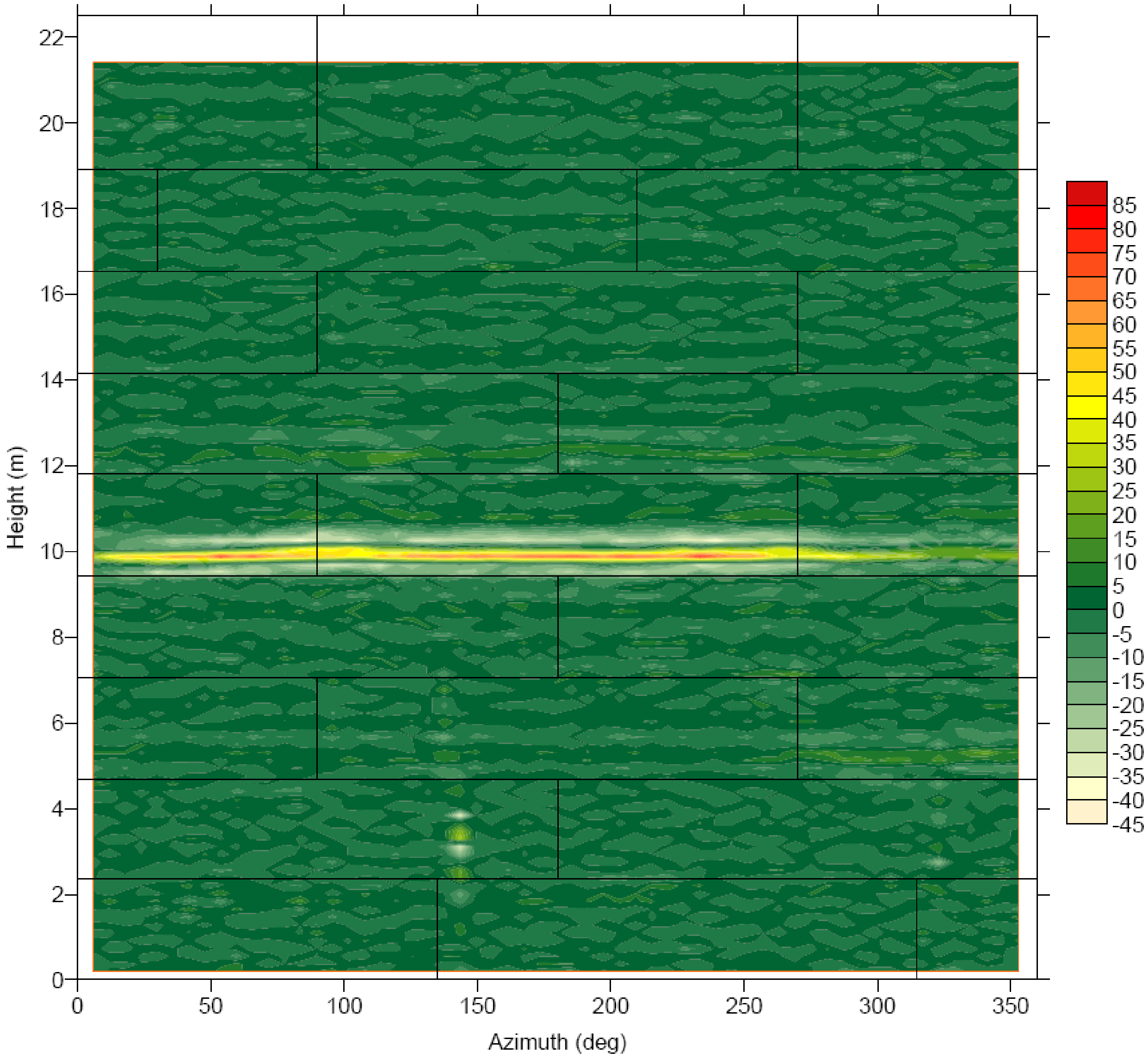

Figure 7 – PSI results.

TABLE 1 – PSI levels related to bulging severity, bulging-related failures, and recommended frequency of laser scanning.

PSI Magnitude	Severity Grade	Likelihood of Bulging-Related Cracks	Recommended Frequency of Laser Scanning
80 to 100%	Failure	Likely	6 months to 1 year
60 to 80%	Danger	Probable	1 year
40 to 60%	Concern	Possible	1 to 2 years
0 to 40%	Design	Unlikely	2 to 3 years

4. Methods comparison

A comparison between these methods can be generically resumed on the Table 2:

Table 2 – Comparative table

Method	Advantages	Disadvantages
Stress analysis (SCF)	Simple analysis Some basis in mechanics	Grossly simplified loading Use of linear elastic model does not account for plastic damage or residual stresses More sensitive to large bulges w/ high aspect ratios Susceptible to significant ovalization error No compliance with industry standards Poor correlation with failures
Strain analysis (PSI)	Excellent correlation with failures Basis in mechanics Not limited to coke drums Based on a recognized industry standard (API 579/ ASME FFS)	Relatively new (2011)

5. Conclusion

- Full internal surface high-density laser scans are needed for precise and high-quality characterization of bulging in coke drums.
- Stress analysis techniques such as SCF have too many technical limitations to be effective for bulging assessment.
- The strain analysis technique PSI correlates well with available data of bulging failures.
- Since PSI is based on the local failure criterion of API 579/ ASME FFS Standard, its results are expected to have more standing with regulatory agencies than stress analysis techniques.

8. References

SAMMAN, MAHMOD, Ph.d., P.e. Assessment of bulging and of bulging and cracking in coke drums, Coking.com Conference & Exhibition, Düsseldorf, Germany,17-21 October 2011.

TRICOM TECNOLOGIA, It-04 Informativo Técnico 03 – Paetc – Programa De Avaliação Estrutural De Reatores De Coque, http://www.tricomtecnologia.com.br/artigos/IT-03%20Informativo%20Tecnico%2003.pdf, Abril 2009.

TRICOM TECNOLOGIA, It-03 Informativo Técnico 04 – Ivr – Inspeção Visual Remota, http://www.tricomtecnologia.com.br/artigos/IT-04%20Informativo%20Tecnico%2004.pdf, September 2008.