

UL'YANOV-TYPE INEQUALITIES AND EMBEDDINGS BETWEEN BESOV SPACES: THE CASE OF PARAMETERS WITH LIMIT VALUES

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Abstract. In this paper we obtain some limit cases of inequalities of Ul'yanov-type for modulus of smoothness between Lorentz-Zygmund spaces on \mathbb{T}^n . Corresponding embedding theorems for the Besov spaces are investigated.

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REFERENCES

- [1] C. BENNETT AND K. RUDNICK, *On Lorentz-Zygmund spaces*, Dissertationes Math. **175** (1980), 1–72.
- [2] C. BENNETT AND R. SHARPLEY, *Interpolation of Operators*, Academic Press, Boston, 1988.
- [3] J. BERGH AND J. LÖFSTRÖM, *Interpolation Spaces. An Introduction*, Springer, Berlin, 1976.
- [4] H. BRÉZIS AND S. WAINGER, *A Note on limiting cases of Sobolev embeddings and convolution inequalities*, Commun. Partial Differ. Equ. **5** (1980), 773–789.
- [5] P. L. BUTZER, H. DYCKHOFF, E. GÖRLICH AND R. L. STENS, *Best trigonometric approximation, fractional order derivatives and Lipschitz classes*, Canad. J. Math. **29** (1977), 781–793.
- [6] A. M. CAETANO, A. GOGATISHVILI AND B. OPIC, *Embeddings and the growth envelope of Besov spaces involving only slowly varying smoothness*, J. Approx. Theory **163** (2011), 1373–1399.
- [7] F. COBOS AND O. DOMÍNGUEZ, *Embeddings of Besov spaces of logarithmic smoothness*, Studia Math. **223** (2014), 193–204.
- [8] F. COBOS AND O. DOMÍNGUEZ, *Approximation spaces, limiting interpolation and Besov spaces*, J. Approx. Theory **189** (2015), 43–66.
- [9] F. COBOS AND O. DOMÍNGUEZ, *On Besov spaces of logarithmic smoothness and Lipschitz spaces*, J. Math. Anal. Appl. **425** (2015), 71–84.
- [10] F. COBOS AND O. DOMÍNGUEZ, *On the relationship between two kinds of Besov spaces with smoothness near zero and some other applications of limiting interpolation*, J. Fourier Anal. Appl. **22** (2016), 1174–1191.
- [11] F. COBOS, L. M. FERNÁNDEZ-CABRERA, T. KÜHN AND T. ULLRICH, *On an extreme class of real interpolation spaces*, J. Funct. Anal. **256** (2009), 2321–2366.
- [12] F. COBOS AND T. KÜHN, *Equivalence of K - and J -methods for limiting real interpolation spaces*, J. Funct. Anal. **261** (2011), 3696–3722.
- [13] R. A. DEVORE AND G. G. LORENTZ, *Constructive Approximation*, Springer, Berlin, 1993.
- [14] R. A. DEVORE, S. D. RIEMENSCHNEIDER AND R. C. SHARPLEY, *Weak interpolation in Banach spaces*, J. Funct. Anal. **33** (1979), 58–94.
- [15] Z. DITZIAN, *Some remarks on approximation theorems on various Banach spaces*, J. Math. Anal. Appl. **77** (1980), 567–576.
- [16] Z. DITZIAN, *Rearrangement invariance and relations among measures of smoothness*, Acta Math. Hung. **135** (2012), 270–285.
- [17] Z. DITZIAN AND A. PRYMAK, *Nikol'skii inequalities for Lorentz spaces*, Rocky Mountain J. Math. **40** (2010), 209–223.

- [18] Z. DITZIAN AND S. TIKHONOV, *Ul'yanov and Nikol'skii-type inequalities*, J. Approx. Theory **133** (2005), 100–133.
- [19] D. E. EDMUNDS AND W. D. EVANS, *Hardy Operators, Function Spaces and Embeddings*, Springer, Berlin, 2004.
- [20] D. E. EDMUND, P. GURKA AND B. OPIC, *Double exponential integrability of convolution operators in generalized Lorentz-Zygmund spaces*, Indiana Univ. Math. J. **44** (1995), 19–43.
- [21] D. E. EDMUND, P. GURKA AND B. OPIC, *Double exponential integrability, Bessel potentials and embedding theorems*, Studia Math. **115** (1995), 151–181.
- [22] D. E. EDMUND AND B. OPIC, *Limiting variants of Krasnosel'skii's compact interpolation theorem*, J. Funct. Anal. **266** (2014), 3265–3285.
- [23] W. D. EVANS AND B. OPIC, *Real interpolation with logarithmic functors and reiteration*, Canad. J. Math. **52** (2000), 920–960.
- [24] W. D. EVANS, B. OPIC AND L. PICK, *Interpolation of operators on scales of generalized Lorentz-Zygmund spaces*, Math. Nachr. **182** (1996), 127–181.
- [25] W. D. EVANS, B. OPIC AND L. PICK, *Real interpolation with logarithmic functors*, J. Inequal. Appl. **7** (2002), 187–269.
- [26] A. GOGATISHVILI, B. OPIC, S. TIKHONOV AND W. TREBELS, *Ulyanov-type inequalities between Lorentz-Zygmund spaces*, J. Fourier Anal. Appl. **20** (2014), 1020–1049.
- [27] A. GOGATISHVILI, B. OPIC AND W. TREBELS, *Limiting reiteration for real interpolation with slowly varying functions*, Math. Nachr. **278** (2005), 86–107.
- [28] A. GOGATISHVILI, L. PICK AND J. SCHNEIDER, *Characterization of a rearrangement-invariant hull of a Besov space via interpolation*, Rev. Mat. Complut. **25** (2012), 267–283.
- [29] M. L. GOL'DMAN, *Embedding of constructive and structural Lipschitz spaces in symmetric spaces*, Proc. Steklov Inst. Math. **173** (1987), 93–118.
- [30] J. GUSTAVSSON, *A function parameter in connection with interpolation of Banach spaces*, Math. Scand. **42** (1978), 289–305.
- [31] D. D. HAROSKE AND H. TRIEBEL, *Embeddings of function spaces: a criterion in terms of differences*, Complex Var. Elliptic Equ. **56** (2011), 931–944.
- [32] V. I. KOLYADA, *Rearrangements of functions and embedding theorems*, Russian Math. Surveys **44** (1989), 73–117.
- [33] E. NURSULTANOV AND S. TIKHONOV, *A sharp Remez inequality for trigonometric polynomials*, Constructive Approx. **38** (2013), 101–132.
- [34] H.-J. SCHMEISSER AND H. TRIEBEL, *Topics in Fourier Analysis and Function Spaces*, Wiley, Chichester, 1987.
- [35] B. SIMONOV AND S. TIKHONOV, *Sharp Ul'yanov-type inequalities using fractional smoothness*, J. Approx. Theory **162** (2010), 1654–1684.
- [36] E. M. STEIN AND G. WEISS, *Introduction to Fourier Analysis on Euclidean Spaces*, Princeton Univ. Press, Princeton, 1971.
- [37] S. TIKHONOV, *On modulus of smoothness of fractional order*, Real Anal. Exchange **30** (2004/2005), 507–518.
- [38] W. TREBELS, *Inequalities for moduli of smoothness versus embeddings of function spaces*, Arch. Math. (Basel) **94** (2010), 155–164.
- [39] H. TRIEBEL, *Interpolation Theory, Function Spaces, Differential Operators*, North-Holland, Amsterdam, 1978.
- [40] P. L. UL'YANOV, *The imbedding of certain function classes H_p^ω* , Math. USSR-Izv. **2** (1968), 601–637.
- [41] U. WESTPHAL, *An approach to fractional powers of operators via fractional differences*, Proc. Lond. Math. Soc. III (Ser. **29**) (1974), 557–576.