

## SOME HARDY AND CARLESON MEASURE SPACES ESTIMATES FOR BOCHNER-RIESZ MEANS

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**Abstract.** In this paper, we show that the Bochner-Riesz means are bounded on weighted and variable Hardy spaces by using the finite atomic decomposition theories. The boundedness of Bochner-Riesz means on weighted and variable Carleson measure spaces is also obtained. Moreover, we also prove that the maximal Bochner-Riesz means are bounded from weighted or variable Hardy spaces to weighted or variable Lebesgue spaces.

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### REFERENCES

- [1] K. F. ANDERSEN, R. T. JOHN, RUSSEL, *Weighted inequalities for vector-valued maximal functions and singular integrals*, Studia Math., **69**, 1 (1980/81), 19–31.
- [2] S. BOCHNER, *Summation of multiple Fourier series by spherical means*, Trans. Amer. Math. Soc., **40**, (1936), 175–207.
- [3] D. CRUZ-URIBE AND A. FIORENZA, *Variable Lebesgue Spaces: Foundations and Harmonic Analysis*, Birkhäuser, Basel, 2013.
- [4] D. CRUZ-URIBE, A. FIORENZA, J. MARTELL AND C. PÉREZ, *The boundedness of classical operators on variable  $L^p$  spaces*, Ann. Acad. Sci. Fenn. Math., **31**, (2006), 239–264.
- [5] D. CRUZ-URIBE, J. MARTELL AND C. PÉREZ, *Weights, extrapolation and the theory of Rubio de Francia*, Birkhäuser, Basel, 2011.
- [6] D. CRUZ-URIBE, K. MOEN AND H. V. NGUYEN, *A new approach to norm inequalities on weighted and variable Hardy spaces*, Ann. Acad. Sci. Fenn. Math., **45**, (2020), 175–198.
- [7] D. CRUZ-URIBE AND L. WANG, *Variable Hardy spaces*, Indiana Univ. Math. J., **63**, 2 (2014), 447–493.
- [8] L. DIENING, *Maximal function on Musielak-Orlicz spaces and generalized Lebesgue spaces*, Bull. Sci. Math., **129**, 8 (2005), 657–700.
- [9] L. DIENING, P. HARIULEHTO, P. HÄSTÖ AND M. RŮŽIČKA, *Lebesgue and Sobolev spaces with variable exponents*, Springer, Heidelberg, 2011.
- [10] J. DUOANDIKOETXEA, *Fourier analysis*, American Mathematical Society, Providence, RI, 2001.
- [11] Y.-C. HAN, Y.-S. HAN, *Boundedness of composition operators associated with mixed homogeneities on Lipschitz spaces*, Math. Res. Lett. **23**, 5 (2016), 1387–1403.
- [12] Y.-C. HAN, Y.-S. HAN, J. LI, *Geometry and Hardy spaces on spaces of homogeneous type in the sense of Coifman and Weiss*, Sci. China Math., **60**, 11 (2017), 2199–2218.
- [13] Y.-C. HAN, Y.-S. HAN, J. LI, *Criterion of the boundedness of singular integrals on spaces of homogeneous type*, J. Funct. Anal. **271**, 12 (2016), 3423–3464.
- [14] Y.-C. HAN, Y.-S. HAN, J. LI, C.-Q. TAN, *Hardy and Carleson measure spaces associated with operators on spaces of homogeneous type*, Potential Anal. **49**, 2 (2018), 247–265.
- [15] Y.-S. HAN, J. LI, L. WARD, *Hardy space theory on spaces of homogeneous type via orthonormal wavelet bases*, Appl. Comput. Harmon. Anal. **45**, 1 (2018), 120–169.
- [16] M.-Y. LEE, *Weighted norm inequalities of Bochner-Riesz means*, J. Math. Anal. Appl., **324**, (2006), 1274–1281.

- [17] M.-Y. LEE, C.-C. LIN AND Y.-C. LIN, *A wavelet characterization for the dual of weighted Hardy spaces*, Proc. Amer. Math. Soc., **137**, (2009), 4219–4225.
- [18] J. LI, L. WARD, *Singular integrals on Carleson measure spaces  $CMO^p$  on product spaces of homogeneous type*, Proc. Amer. Math. Soc., **141**, 8 (2013), 2767–2782.
- [19] S. LU, *Four Lectures on Real  $H^p$  spaces*, World Scientific Publishing, River Edge, N. J., 1995.
- [20] E. NAKAI AND Y. SAWANO, *Hardy spaces with variable exponents and generalized Campanato spaces*, J. Funct. Anal., **262** (2012), 3665–3748.
- [21] P. SJÖLIN, *Convolution with oscillating kernels in  $H^p$  spaces*, J. London Math. Soc., **23**, (1981), 442–454.
- [22] E.M. STEIN, M.H. TAIBLESON, G. WEISS, *Weak type estimates for maximal operators on certain  $H^p$  classes*, Rend. Circ. Mat. Palermo 2, (Suppl. 1), (1981), 81–97.
- [23] J.-O. STRÖMBERG, A. TORCHINSKY, *Weighted Hardy spaces*, Lecture Notes in Mathematics, 1381. Springer-Verlag, Berlin, 1989.
- [24] J. TAN, *Discrete para-product operators on variable Hardy spaces*, Can. Math. Bull., **63**, 2 (2020), 304–317.
- [25] J. TAN, *Carleson measure spaces with variable exponents and their applications*, Integral Equations Operator Theory, **91**, 5 (2019), 91:38.
- [26] J. TAN, *Atomic decomposition of variable Hardy spaces via Littlewood-Paley-Stein theory*, Ann. Funct. Anal., **9**, 1 (2018), 87–100.
- [27] J. TAN, *Weighted Hardy and Carleson measure spaces estimates for fractional integrations*, (2019), preprint.
- [28] J. TAN, Y.-C. HAN, *Inhomogeneous multi-parameter Lipschitz spaces associated with different homogeneities and their applications*, Filomat, **32**, 9 (2018), 3397–3408.
- [29] H. WANG, *Boundedness of Bochner-Riesz operators on weighted weak Hardy spaces (Chinese)*, Acta Math. Sinica (Chin. Ser.), **56**, 4 (2013), 505–518.
- [30] D. YANG, W. YUAN, C. ZHUO, *A survey on some variable function spaces*, Function spaces and inequalities, 299–335, Springer Proc. Math. Stat., 206, Springer, Singapore, 2017.
- [31] D. YANG, C. ZHUO, E. NAKAI, *Characterizations of variable exponent Hardy spaces via Riesz transforms*, Rev. Mat. Complut., **29**, (2016), 245–270.
- [32] C. ZHUO, D. YANG, Y. LIANG, *Intrinsic square function characterizations of Hardy spaces with variable exponents*, Bull. Malays. Math. Sci. Soc., **39**, 4 (2016), 1541–1577.