

## SERIES REPRESENTATIONS OF THE REMAINDERS IN THE EXPANSIONS FOR CERTAIN TRIGONOMETRIC FUNCTIONS AND SOME RELATED INEQUALITIES, I

CHAO-PING CHEN AND RICHARD B. PARIS

*Abstract.* We present series representations of the remainders in the expansions for certain trigonometric and hyperbolic functions. From these results, we establish some inequalities for trigonometric and hyperbolic functions.

*Mathematics subject classification (2010):* 11B68, 26D05.

*Keywords and phrases:* Bernoulli numbers, Euler numbers, trigonometric function, hyperbolic function, inequalities.

### REFERENCES

- [1] M. ABRAMOWITZ AND I. A. STEGUN (eds.), *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables*, National Bureau of Standards, Applied Mathematics Series **55**, 9th printing, Washington, 1970.
- [2] B. BANJAC, M. MAKRAĐIĆ AND B. MALEŠEVIĆ, *Some notes on a method for proving inequalities by computer*, Results. Math. **69**, 1 (2016), 161–176.
- [3] M. BECKER AND E. L. STRAK, *On a hierarchy of quonynomial inequalities for  $\tan x$* , Univ. Beograd. Publ. Elektrotehn. Fak. Ser. Mat. Fiz. No. **602–633** (1978), 133–138.
- [4] C.-P. CHEN AND W.-S. CHEUNG, *Sharp Cusa and Becker–Stark inequalities*, J. Inequal. Appl. **2011** (2011), 136, <http://www.journalofinequalitiesandapplications.com/content/2011/1/136>.
- [5] C.-P. CHEN AND R. B. PARIS, *Series representations of the remainders in the expansions for certain functions with applications*, Results. Math. 2016, DOI: 10.1007/s00025-016-0612-1.
- [6] C.-P. CHEN AND F. QI, *A double inequality for remainder of power series of tangent function*, Tamkang J. Math. **34**, 4 (2003), 351–355.
- [7] C.-P. CHEN AND J. SÁNDOR, *Sharp inequalities for trigonometric and hyperbolic functions*, J. Math. Inequal. **9**, 1 (2015), 203–217.
- [8] L. DEBNATH, C. MORTICI AND L. ZHU, *Refinements of Jordan–Stečkin and Becker–Stark inequalities*, Results Math. **67** (2015), 207–215.
- [9] H.-F. GE, *New sharp bounds for the Bernoulli numbers and refinement of Becker–Stark inequalities*, J. Appl. Math. **2012**, Article ID 137507, 7 pages.
- [10] I. S. GRADSHTEYN AND I. M. RYZHIK, *Table of integrals, series, and products*, translated from the Russian, Sixth edition, translation edited and with a preface by Alan Jeffrey and Daniel Zwillinger, Academic Press, Inc., San Diego, CA, 2000.
- [11] S. KOUMANDOS, *On completely monotonic and related functions*, Mathematics Without Boundaries, pp. 285–321. Springer, New York, 2014.
- [12] Y. NISHIZAWA, *Sharp Becker–Stark’s type inequalities with power exponential functions*, J. Inequal. Appl. 2015 (2015) 402, <http://rd.springer.com/article/10.1186/s13660-015-0932-9/fulltext.html>.
- [13] F. W. J. OLVER, D. W. LOZIER, R. F. BOISVERT, C. W. CLARKS (eds.), *NIST Handbook of Mathematical Functions*, Cambridge University Press, New York, 2010.

- [14] Z.-J. SUN AND L. ZHU, *Simple proofs of the Cusa–Huygens–type and Becker–Stark–type inequalities*, J. Math. Inequal. **7** (2013), 563–567.
- [15] J.-L. ZHAO, Q.-M. LUO, B.-N. GUO AND F. QI, *Remarks on inequalities for the tangent function*, Hacet. J. Math. Stat. **41**, 4 (2012), 499–506.
- [16] L. ZHU, *Sharp Becker-Stark-type inequalities for Bessel functions*, J. Inequal. Appl. **2010**, Article ID 838740, 4 pages.
- [17] L. ZHU, *A refinement of the Becker-Stark inequalities*, Math. Notes **93** (2013), 421–425.
- [18] L. ZHU AND J. K. HUA, *Sharpening the Becker-Stark inequalities*, J. Inequal. Appl. **2010**, Article ID 931275, 4 pages.